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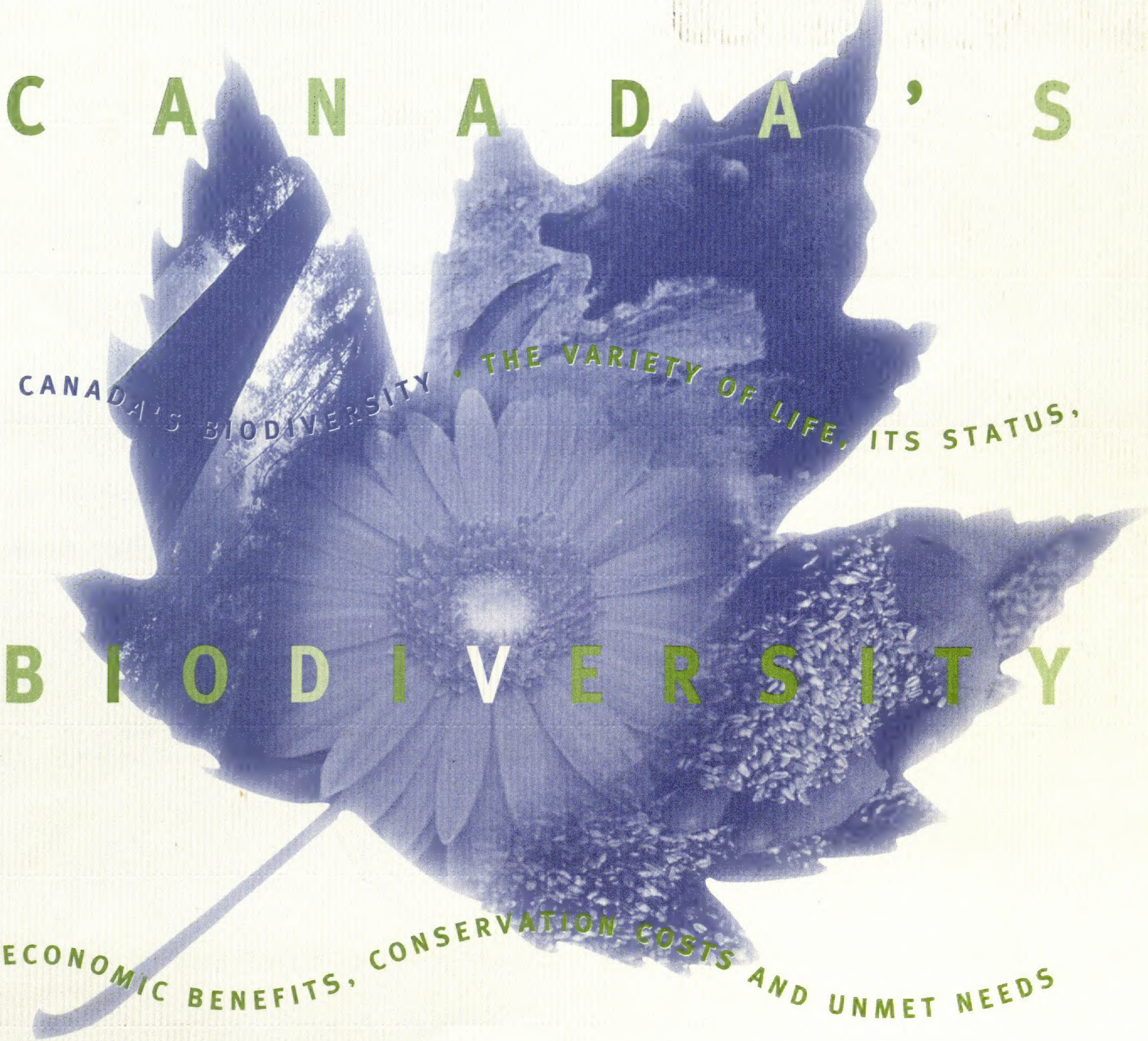
CANADA'S BIODIVERSITY, THE VARIETY OF LIFE, ITS STATUS, ECONOMIC BENEFITS, CONSERVATION COSTS AND UNMET NEEDS



BY TED MOSQUIN, PETER G. WHITING, DON E. McALLISTER

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CANADA'S BIODIVERSITY

CANADA'S BIODIVERSITY:

The Variety of Life, Its Status, Economic Benefits, Conservation Costs and Unmet Needs

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Best wishes Peter:
From your
old friend
Ted

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Published by Canadian Museum of Nature, P.O. Box 3443, Station D, Ottawa, ON, Canada K1P 6P4

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CANADIAN CATALOGUING IN PUBLICATION DATA

Mosquin, Ted, 1932-

Canada's biodiversity: the variety of life, its status, economic benefits, conservation costs and unmet needs
Includes bibliographical references.

ISBN 0-660-13073-4

1. Biological diversity — Canada. 2. Biological diversity conservation — Canada.
I. Whiting, Peter G. II. McAllister, Don E., 1934- III. Canadian Museum of Nature. IV. Title.
V. Title: The variety of life, its status, economic benefits, conservation costs and unmet needs.
QH77.C3M67 1995 574.'0971 C95-980201-0

Catalogue No: NM98-13/7-1995E

Henderson Book Series No. 23

Henderson Book Series honours the kind and generous donation of Mrs. Arthur T. Henderson that made this series possible. The Canadian Parks and Wilderness Society gratefully acknowledges Mrs. Henderson's support of the Society's efforts to promote public awareness of the value of Canada's park and wilderness areas.

Special thanks to the Biodiversity Convention Office, Environment Canada, for providing the translation of this book.

Managing Editor: Dawn Arnold

Editors: Lauren Walker, Sarah Schmidt

Design: Karen Temple, Carrie Colton

Illustrations: Roelof Idema, from *Global biodiversity,* courtesy of The Canadian Museum of Nature (unless otherwise credited)

Printed and bound in Canada using 100% recycled paper.

QH77
.C2
M67
1995

CANADA'S

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BIODIVERSITY

ECONOMIC BENEFITS, CONSERVATION COSTS AND UNMET NEEDS

BY TED MOSQUIN, PETER G. WHITING, AND DON E. McALLISTER

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FOREWORD

From the outset, Canada has actively supported the interests and endeavours of the United Nations Environment Program (UNEP) to define and carry out Country Studies on biodiversity in different nations. Recognizing the importance of this work as seminal to appreciating and mapping the vastness and interconnectedness of biodiversity and to understanding the costs of conserving and the benefits derived from biodiversity, Canada played a key role in the UNEP "Expert Committees" that developed and refined the guidelines upon which Country Studies carried out to date have been based. In this spirit, Canada completed its own country study, directly supported Costa Rica's, and provided advice and assistance to other countries.

Canada, in fact, began its Country Study over four years ago when the Canadian Museum of Nature carried out the first "national inventory of biodiversity" ever to be attempted by a nation. This initial biological report was enhanced to include an analysis of economic costs and benefits. In attempting to meet UNEP Guidelines for this Country Study, many insights regarding the gaps in our biological knowledge and the accuracy of our understanding of its real benefits have surfaced. Assembling the necessary biological information, having it reviewed and ensuring that it is properly measured and evaluated in economic terms has been a mammoth task. Despite its incompleteness in many areas and its need for refinement in others, this study underscores the importance of inventory, research, and economic assessment of Canada's biodiversity and the extraordinary value that such information will have in guiding the decisions of this country's leaders.

Not surprisingly, the report's findings indicate that Canada's overall biodiversity is declining. The benefits that accrue from it are grossly underestimated and are only just beginning to be more carefully calculated. Traditional methods for economic assessment have serious shortcomings and often stimulate overexploitation of biological resources rather than encourage their sustainable use. The harvest of biological resources is an essential component of the well-being of human populations, but it must be tempered with long-term planning that includes the conservation of biodiversity and sustainable management of this nation's biological resources.

The economic analysis of the costs and benefits of biodiversity conservation was the most complex and difficult part of this study. Exacerbated by the frequent incompleteness of the basic biological data, the disparate methods of measurement used by different groups and agencies, and the physical immensity of the nation itself made this a formidable task.

This study is being planned as an evolving document and contains much information that will need to be considered in developing a future strategy and action plan for Canada. As such, it has become recognized as an important tool for refining Canada's understanding of its own biodiversity and its global responsibilities. Its strength is in the questions it brings to bear as Canada seeks to meet its legal commitment to the Convention on Biological Diversity, and our moral commitments to our children and to our fellow species in the family of life.

The opinions and recommendations in this report (presented in the form of options) are those of the authors, who have attempted to draw on the best available knowledge and expertise across Canada within the extraordinary strictures of time and available resources. I would like to express my sincerest gratitude to them for their tireless efforts in making this study possible.

ROBERT McFETRIDGE
Director
The Canadian Centre for Biodiversity
Canadian Museum of Nature

EXECUTIVE SUMMARY

This report brings together a great deal of original information on Canada's biodiversity, a term understood here in its widest sense. The scientific meaning of biodiversity is outlined. The standards by which changes to biodiversity must be judged are presented and the ecological functions or ecoservices of biodiversity are detailed. A taxonomic census of wild species is provided and the state of biodiversity in major ecological zones is appraised. Both *in situ* and *ex situ* conservation measures being taken are outlined. Economic benefits (derived from both wild and cultivated/domesticated/cultured species) are outlined, as are the costs of conservation. A total of 42 options for conserving Canada's biodiversity are provided together with an account of Canada's unmet needs for conserving biodiversity in the longer term.

TAXONOMIC CENSUS

The taxonomic census documented that an approximate total of 71,000 species of micro-organisms, fungi, plants and animals have been reported to occur in Canada (out to the 200-mile offshore limit, within Canada's marine Arctic sector and from the surface down to the sea floor). In addition, a roughly equal number of species (over 68,000) remain undescribed or unreported by science, based on consultation with a wide range of taxonomists and review of taxonomic literature. This means that Canada is home to some 140,000 species of micro-organisms, fungi, plants, and animals. If viruses are added to this total (assuming that each host species supports an average of one virus), the total is doubled to 280,000. Thus, major gaps exist in taxonomic knowledge of our biota. In particular, organisms small in body size are very poorly known taxonomically, even though together they represent an enormous hidden biomass or may provide critical ecological functions necessary to the maintenance of the productivity and health of regional and sectoral ecosystems and their species.

ECOSYSTEM DIVERSITY

Ecosystem diversity is also examined in a general way. It is noted that of the 177 different terrestrial ecoregions (as defined by Environment Canada), about one third are not represented by protected areas, meaning that valued areas may soon be lost. Some ecosystems have been greatly reduced in geographical extent. As well, in some ecoregions, the introduction of exotic species has had serious effects on natural biodiversity including the capacity of ecosystems to function normally. Agriculture, ranching, fisheries, urbanization, and forestry have resulted in major conversions of natural ecosystems and varying losses of biodiversity while contributing to the prosperity of Canadians and the strength of the economy. Pollution of the air, water, and land is also significantly altering Canada's biodiversity. The ecological requirements of only a tiny fraction of Canada's 70,000 described species is reasonably understood, while ecosystem research is scattered, fragmented, or for most ecoregions, non-existent. Funding support for ecological research is marginal even for research underpinning the resource industries, especially in forests, soils, and fisheries. Hence, the understanding of how natural ecosystems work is superficial and deviations from norms are becoming greater. In this situation, strategies and management programs to maintain biodiversity or manage on an ecosystem thinking basis are difficult, impossible, or specious. Ecological sustainability for the country may never be possible to achieve since the parts and processes of the whole are being lost piece by piece and area by area, with the Atlantic cod fishery being the latest example. Between 2% and 3% of Canada's terrestrial ecosystems lie within protected parks, ecological reserves and similar areas. We can say that in such areas biodiversity has been conserved *in situ*. The question should be asked: Is this percentage sufficient to meet the intent of the Convention on Biological Diversity? A national long-term goal of 12% protected spaces was set in Canada's Green Plan, but in 1992, the plan's budget was cut by 24% and in 1995 the plan was terminated. As well, Canada has a goal of securing representative protected areas within each of Canada's 39 terrestrial natural regions as defined by Parks Canada with only one marine protected area despite the longest marine coastline of any nation in the world. Provincial governments have set or are developing their own goals in areas of provincial jurisdiction. Canada has been active with some *ex situ* activities to conserve specifically valued genes, cultures, seeds, trees, and rare or threatened animals.

BIODIVERSITY FUNCTIONS

A total of 21 ecological functions of biodiversity are identified. The functions define the things that organisms and ecosystems *actually do* to maintain the diversity, productivity, and health of local and regional ecosystems and the long-term balances and stability of the planetary ecosphere. The functions are: primary production, oxygen production, herbivory, carnivory, population moderation, nutrient transport (by organisms), sequestering of carbon dioxide, dispersal/migration, control of soil erosion, many types of symbiosis, soil and sediment creation and conditioning, moderation of macro- and microclimate, decomposition, three-dimensional multicellular structures of organisms and ecosystems, communication, food webs, biogeochemcial nutrient cycling (in the ecosphere), maintenance of genetic diversity, stability, community succession, and harmony. Many of these functions provide values and services to the quality and productivity of ecosystems and the planetary ecosphere that have not been measured through the use of traditional economic methods. Biodiversity function values are not calculated in national accounts such as gross domestic product (GDP). It is because of the ecological functions of both organisms and ecosystems that economists can tally up some of the more obvious monetized values of the workings of biodiversity. As well, the explicit identification of biodiversity functions enables one to sense and better visualize the generally unsensed non-monetizable values of biodiversity.

ECONOMICS OF BIODIVERSITY AND BIOLOGICAL RESOURCES

The economics section of this study of biodiversity and biological resources derives estimates of the benefits Canadians and others gain from biological resources; these are defined as "organisms, or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value to humanity." The economics component also examines many of the costs associated with the conservation of biodiversity and biological resources.

The total monetized benefits realized by Canadians from their biological resources was conservatively estimated at $70 billion annually. This value included $31 billion in annual commercial value, $36 billion annually in replacement or imputed values, over $1 billion annually in direct benefits, and up to $1.1 billion in existence and option values. These monetized values, which mostly exclude value-added processing, represent only a portion of the benefits derived from Canada's biological and ecological resources which sustain far larger value-added industries. The ongoing costs of conserving biodiversity were estimated to be under $2 billion at the federal level, with over 2,000 environmental nongovernmental organizations also making significant contributions in time and money.

There are several major areas where further economic research and analysis effort is required. In particular, micro-organisms and ecosystems deserve economists' attention, as well as capital depletion of natural resources in national and provincial accounting, and methodological work on valuations for existence and option values of biological resources. The value of ecological services of biodiversity should be included in national accounts. Research on both benefits and costs is required.

CONCLUSIONS, OPTIONS, AND UNMET NEEDS

A vision statement is presented in Chapter 7 outlining roughly what is needed in terms of land zoning and application of the principles of conservation biology to permanently conserve Canada's biodiversity and to make it possible for Canadians to live in closer harmony with nature's time-tested systems, conserve species, and use biological resources in an ecologically sustainable manner. We visualize that a required 1/3 of land and marine area in each natural region must be retained in (or restored to) its natural state; 1/3 be used in ways that retain the natural range of biodiversity functions within the norms described in this report; and the final 1/3 be zoned principally for direct human uses with the proviso that activities and pollution not be permitted to weaken and degrade overall planetary systems and norms.

A total of 42 options for conserving Canada's biodiversity are presented, aimed at accomplishing the goals of the Convention on Biological Diversity in Canada and at ensuring the permanent conservation and sustainable use of this nation's biodiversity.

Canada's unmet needs were estimated in a preliminary way. These were calculated from the point of view of expansions to existing programs and new programs. While the Federal Government's Green Plan attempted to provide a comprehensive program for environmental conservation in Canada for a five-year period, some additional activities are identified. The total expenditure under the Green Plan was to be $3 billion. Other activities identified in this report add a further $2.8 billion.

ACKNOWLEDGEMENTS

This study was made possible by the valuable assistance and co-operation of the many organizations, agencies, and individuals who provided material, suggestions for additional sources of information, and constructive comments on various drafts of the report.

We are particularly grateful to reviewers who examined earlier drafts of this report and made critical suggestions for improvement. These included Fred Schueler, Geoff Scudder, Stan Rowe, Brad Fraleigh, Tim Boyle, and Andy Hamilton. Special thanks go to Fern Filion and André Jacquemot of the Canadian Wildlife Service, Environment Canada, Ottawa, for their helpful contributions and counsel. Bob McFetridge, Canadian Museum of Nature, provided ongoing encouragement and invaluable assistance with logistics and other support.

This report would not have been possible without John Herity, Director of the Canadian Biodiversity Convention Office, Environment Canada. John led the process of developing negotiating positions of the Canadian delegation to the Convention on Biological Diversity and chaired the development of a Canadian Biodiversity Strategy. He has been a driving force in ensuring that federal sectoral agencies, provincial governments, nongovernmental organizations and the private sectors had an open and democratic opportunity to participate in the development of positions on the Convention and for the Strategy. We thank Dr. H. Zedan of the United Nations Environment Program (UNEP), the federal government departments, provinces, and environmental organizations that reviewed parts of earlier drafts.

Many people from across Canada provided information through phone calls and notes on the varied aspects of biodiversity in their respective fields. These included Theresa Anískowicz George Argus, David Barr, P.F. Barrett, Spencer Barrett, Diane Beaven, Valerie Behan-Pelltier, Caroline Bird, Tom Beechey, Clark Binkley, Ed Bousfield, Tim Boyle, Dave Brand, Keith Brickley, Irwin Brodo, Robert Burchett, Dale Calder, Rick Callaghan, Gisäle Cantin, Paul Catling, Maryse Charbonneau, Rama Chengalath, Ray Chipeniuk, Holly Claremont, David Clarke, Mark Clarke, Sylvain Cloutier, Bill Cody, Guellermo Contreras, Francis Cook, Paul Cook, Clarke Corbo, Bruce Crouter, Don Cuddy, John Cunningham, Ken Curnew, Phuoc Dang, Charles Dauphiné, Kathryn DeCarlo, Joanne DeCosimo, C. Dondale, Don Eastman, B.A. Ebsary, Rob Enns, Ron Erickson, T. Erskine, Fern Filion, D. Findlay, Robbin Fisher, Judith Fournier, George Francis, Stephen Fuller, Fundy Deer Farmers Ltd., Suzanne Gailloux, James Gardner, David Gauthier, Val Geist, Jim Ginns, Dave Gordon, R.A. Haines, Paul Hamilton, Vernon Harms, Paul Hartley, David Hawksworth, Gail Hinch, Paula Hudson, Monte Hummel, Tom Hutchinson, Bob Ireland, André Jacquemot, Ralph Jarvis, David Jarzen, Bryce Kendrick, Kathy Knox, Bernard Jackson, Meredith Jones, Wilf Jurke, Barry Kaufmann, Don Lafontaine, Richard Laing, Philip Lambert, Daniel Lang, Diana Laubitz, Clarence LeBreton, David Leeb, Raymond Lemieux, Peter Letkeman, Ken Lloyd, Kevin Lloyd, J. Lynn, J.A. MacLean, Victorin Mallet, Edward Manning, Paul Marriage, Lubomir Masner, Gordon Mason, A.T. Matheson, Bruce McGillivray, B.A. McKeown, Bob McLeod, Ann McWilliam, John Middleton, Bob Milko, Carol Morin, E. Morin, Douglas G. Murray, Robert Murray, David Neave, Ross Norstrom, Reed F. Noss, Michael Oldham, Henri Ouellet, Valerie Pasztor, Luc Perron, Frances Pick, Michel Poulin, Tom Powers, Scott Redhead, Henry Reiswig, Peter Rice, Helen Richard, Patricia Roberts-Pichette, Jim Robertson, John Robertson, Keith Ronald, Clive Roots, Stan Rowe, Brian Segal, Fred Schueler, Geoff Scudder, Gerald Straley, Anne Tessier, Diane Thorpe, Jane Topping, C. van Zyll de Jong, L.P. Visentin, Bert Vissers, K.C. Watts, Mark Williams, Dale Wilson and Wilma Wood.

We wish to acknowledge the efforts of Melissa Abbott, Sheila Barker, Ron Huizer, Richard Pither, and Noel Alfonso, who provided research assistance for draft versions of this report.

Funding was provided by Environment Canada and the Canadian Museum of Nature and is gratefully acknowledged.

CHAPTER I

INTRODUCTION

This report contains information from a wide range of sources defining the current status and value of Canada's biodiversity and biological resources. The study also sought to gain some preliminary insights into the levels of effort, commitment, and resources required to conserve and/or restore the country's biodiversity to the degree that would ensure its survival at a healthy, ecologically sustainable and productive level.

The origins of this "Country Study" stem from preparations for the Convention on Biological Diversity, which was signed by 150 nations at the Earth Summit in Brazil in June, 1992, and which came into force December 29, 1993, following ratification by the 30th nation. The convention came about because of a worldwide concern about the continuing loss of species and the destruction of ecological systems in all nations. Tens of thousands of species, subspecies, and locally adapted races containing unique genetic material continue to vanish while ever more species and unique races come into risk of extinction. Overharvesting of the planet's natural productivity continues on an unsustainable scale. Many biological and ecological resources (fish, forests, reefs, soils) are also being seriously affected by pollution.

The United Nations Environment Program (UNEP) recognized this increasingly desperate issue, and in 1990, held meetings with experts from around the world to initiate a global program that would determine the biodiversity present in each country and identify conservation requirements. Many countries have carried out similar studies, and many more have indicated a wish to participate. This report represents the results of what has become known as the "Canada Country Study of Biodiversity". Its underlying purpose is to determine the state of this nation's biodiversity and what it would take to permanently conserve the naturally existing organisms, ecosystems, ecological processes, and important biological resources of the nation.

The report begins by examining the scientific meaning of biodiversity and biological resources. It then sets out the standards by which the state of biodiversity must be measured in an area or region. This is followed by a detailed analysis of what biodiversity does (the functions of species and ecosystems) locally, regionally, and for the ecosphere as a whole. On the basis of these criteria, the state or status of Canada's biodiversity is then examined. A chapter on economic valuation examines a myriad of sources of socio-economic benefits derived from Canada's biological and ecological resources and looks at costs associated with biodiversity conservation. Chapter 7 provides 42 options for conserving Canada's biodiversity based on the findings of the study. The chapter also estimates Canada's unmet needs for biodiversity conservation.

A Country Study can be viewed as a vehicle for providing data as well as a means of initiating discussions and examining options for the development of action plans to permanently conserve and to intelligently use the nation's and the planet's biodiversity. Detailed tables and appendices for Canada are provided. These, together with the references, contain much of the essential information and sources upon which the report's findings and options are based.

While the perspectives put forward in this report are those of the authors, the report has been strengthened as a result of input from many individuals in the provinces, Environment Canada, the Canadian Museum of Nature, Agriculture Canada, Fisheries and Oceans Canada, some nongovernmental organizations, and the many individuals listed in the acknowledgements. The courses of action suggested here do not represent official positions of the federal, provincial, or territorial governments. The authors believe, however, that these recommendations and options generally reflect the direction respecting the conservation of biodiversity in which increasing numbers of Canadians are moving or have indicated they are interested in moving.

Several important aspects of biodiversity and biological resources were not examined in this report. A further significant research/analysis effort within a much larger time frame is required. Specific and more manageable subject areas should be researched in detail, some conceptual and practical problems could be overcome for reporting in future. To minimize costs and to obtain maximum credibility, the proposed updates to this study should be carried out at arm's length from government and should be supported by an adequate budget. (The authors spent a substantial amount of volunteer time to produce this report.)

This study is considered to be a first approximation that should be updated at intervals of not less than five years using the new UNEP guidelines. Prior to the first update, the matter of monitoring for the conservation of biodiversity should be examined. In particular, what should be monitored should be determined (see Option 20 in Chapter 7).

1.1 THE CANADIAN CONTEXT

Canada is the second-largest nation in the world, encompassing a land mass of 9.9 million km^2; its 200 nautical mile exclusive fishing zones and the arctic sector (i.e. the ocean area east of the line between the Alaska/Yukon border and the North Pole, and west of the line between Canada and Greenland, and the northeast tip of Ellesmere Island and the North Pole) span an additional 6.5 million km^2. Bordering on three oceans Canada's coastline stretches for 224,000 km. Such a vast area naturally incorporates a wide variety in terrain. Any portrayal of Canada must include the rugged heights of the Rocky Mountains along with the rolling prairies/grainfields, the Canadian shield, vast arctic tundra and, until recently, the fish-rich Grand Banks. The climate shows considerable latitudinal variation as well, ranging from temperate in the southern sections of the country to dry winter cold (coupled with winter darkness) in the arctic regions where cool summers are short.

Politically, Canada is divided into ten provinces and two territories, with the establishment of a new territory, Nunavut, currently being developed. Jurisdiction over biodiversity and biological resources is often shared, although each province administers and regulates uses of lands, forests, water, and most

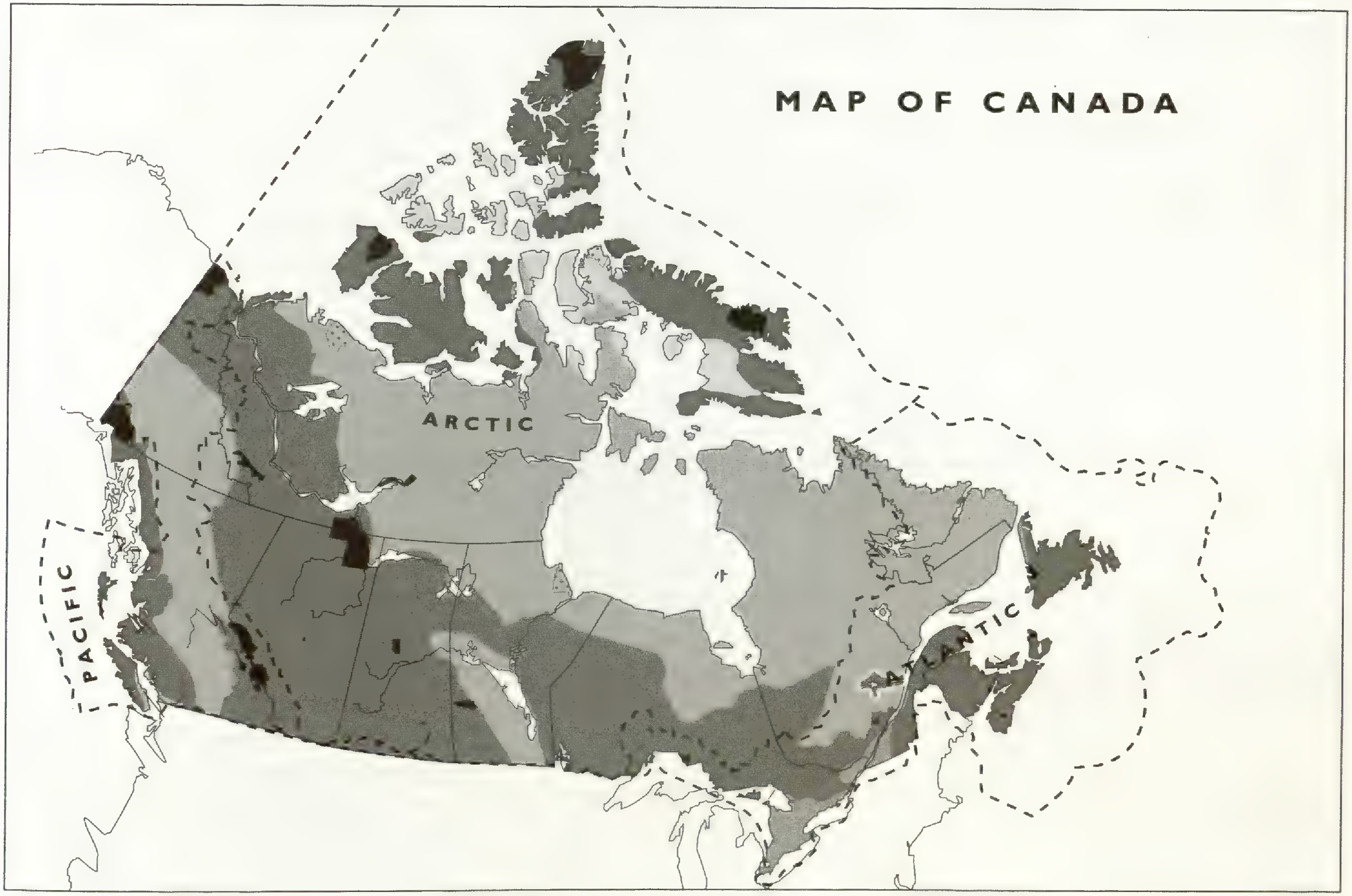

MAP OF CANADA
ARCTIC
PACIFIC
ATLANTIC

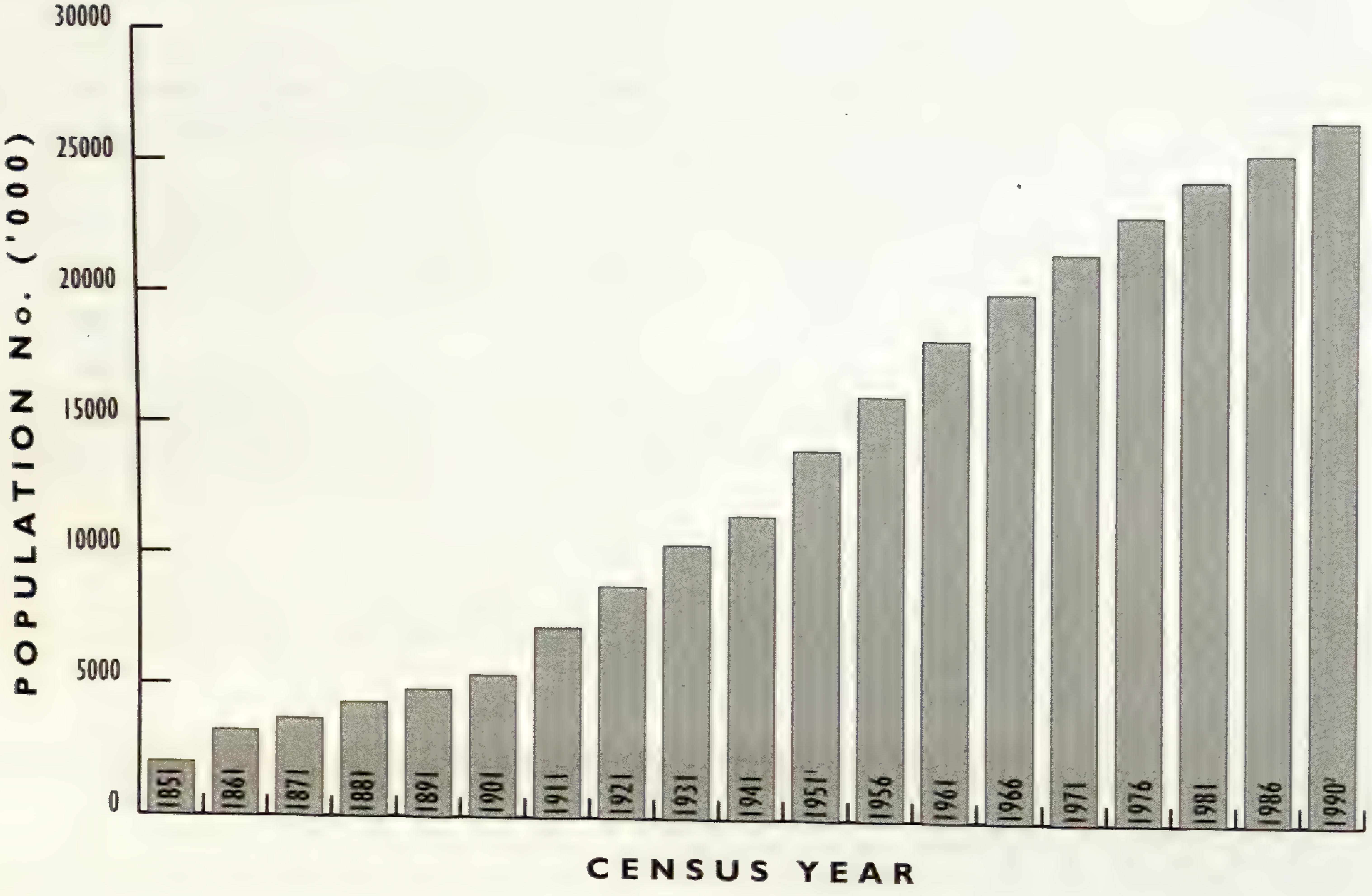
FIGURE 1

Map of Canada showing lines marking the 200 mile limit, the continental divide, and the pacific and arctic sectors. Canada is the world's second-largest country with over 9.9 million km^2 of lands and freshwaters.

wildlife within its borders; the federal government has jurisdiction over marine fisheries and migratory birds while delegating freshwater fisheries in some provinces. In the Yukon and Northwest Territories, the federal government retains control over most of the land and its use, while the territorial governments have responsibility for wildlife and forests. The federal government regulates the uses of migratory birds and offshore marine fisheries and areas.

The majority of Canada's 27 million inhabitants live within 200 km of the Canada/U.S. border. The most densely populated areas are southern Ontario, Quebec, and southwestern British Columbia, which are also more industrialized than the rest of the country.

Compared with most other countries, the range of ecosystems is vast, and includes marine areas with rocky reefs and shorelines with kelp beds, fishing banks, continental slopes, deep ocean basins and trenches, arctic ocean, deciduous forests, boreal forests, grasslands, arid forest, pockets of desert, widespread tundra, mountain valleys and alpine areas and temperate rain forests on the west coast. Species in Canada have had to adapt to snow and cold by insulation, freeze tolerance, supercooling, circulatory heat exchangers, dietary changes, fat storage,



[1] Newfoundland included for the first time. Excluding Newfoundland, the increase would have been 2,141,358 or 18.6%.

[2] Updated postcensal estimates.

FIGURE 2

Population growth for Canada over the last hundred years. Insets show the current proportion of population growth, highest amongst G7 nations, attributable to immigration. Although Canada has a low population density, its high per capita rates of consumption make its present population the equivalent of one billion persons in some less developed countries.

migration and innumerable life cycle modifications including burrowing in the snow and hibernation. Life cycle adaptations can be particularly unusual for species adapted to life on the underside of, or beneath the arctic ice.

Canada is a country rich in forests, fisheries, soils, fresh waters, wildlife, and minerals. Historically, these resources have provided the basis for Canada's wealth. Forestry, fisheries, and agricultural production are the basis for much of the nation's economic wealth and have also been the stimulus for most other commercial and economic activities. The country is internationally perceived as having a clean environment a positive situation that has traditionally provided the basis for travel, tourism and other service industries. However, a recent state of the environment report (Environment Canada 1991b) concluded that Canada's environment is in serious trouble and projected that ecological degradation will continue and even accelerate.

In 1990, the federal government produced a Green Plan (Environment Canada 1990) that set forth some priorities and provided funding for a number of initiatives. However, the economic and political climates that developed over the next few years led to much reduction in funding of the Green Plan. In 1995, the federal government terminated the Plan. As this document goes to press, a draft Canadian Biodiversity Strategy prepared by federal, provincial, and territorial governments with input from industry, nongovernmental organizations, indigenous peoples and academe, has been completed. Some provincial and territorial initiatives — for example, the recently announced Yukon Conservation Strategy, and British Columbia's biodiversity conservation strategy, which are aimed at better biodiversity conservation) offer a flickering ray of hope that the extensive talk and plethora of documents about biodiversity conservation will actually make some difference in the future. Whether or when this will begin to happen, only time will tell.

CHAPTER 2

THE SCIENTIFIC AND ECONOMIC MEANING OF BIODIVERSITY

In this report, biodiversity is clearly distinguished from biological resources. Biodiversity has a very broad, all-inclusive meaning, while the term biological resources (section 2.2), as defined by the Convention on Biological Diversity, refers to the economic aspect of biodiversity.

2.1 BIODIVERSITY

The Convention on Biological Diversity adopted at the Earth Summit in June 1992 defined biological diversity as *"variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part."* The unfortunate vagueness and complexity of the definition was caused by political processes irrespective of scientific thinking and knowledge. Hence, for this report, the real meaning of biodiversity is provided. There are two ways of defining this new word. First, biodiversity must be defined in a broad sense to serve the requirements of general discussion, and second, the scientific meaning needs to be outlined.

There are two short sentences in the literature which, when taken together, encapsulate the real meaning of biodiversity in the general sense, and these are worth committing to memory. The first is that of Salwasser (1991) in a report for the U.S. Congress: *"the variety of life and its processes in an area."* The second is that of Council on Environmental Quality, Washington (CEQ 1993): "*the popular way of recognizing the ecological concept that everything is connected to everything else.*" The four key words in these sentences are *variety, processes*, *connected,* and *area*. Area means the space required for biodiversity to thrive. Without area, resource agencies cannot point to specific pieces of land and water needed to conserve biodiversity within a jurisdiction, thus making it possible for them to effectively avoid meaningful conservation efforts.

The principal components of biodiversity have been explored and reviewed by many recent authors (Rowe 1990a; McAllister 1991d; Keystone Centre 1991; Global Monitoring Centre 1992; Wilson 1992). A basic biodiversity reference library has been prepared by McAllister (1993). At the scientific level, a fairly comprehensive definition is that of Noss 1990) and Hughes & Noss (1992):

"[biodiversity is] the variety of life and its processes and encompasses genetic, species, assemblage, ecosystem and landscape levels of biological organization and their structural, compositional and functional components."

Biodiversity is an objective and precise word for "nature" and may help explain why this term has been adopted by people who view the emotional connotations of the preservation of "nature" with some hostility. Biodiversity is also one of those rare "bringing together" words rather than a "taking apart word" of which humanity has many thousands. Biodiversity can be compared with words like ecosystem, biosphere, evolution, ecosphere, integrity, and the like. Its use should help to bring people and the planet closer together. One of the curses of our species is the process of "thinking the world to pieces", cutting it up, compartmentalizing our thoughts about it, researching details, and fragmenting landscapes, while avoiding thought about the importance of preserving the workings of the whole. Biodiversity knowledge and thinking invites one to look outwardly at the world, become less absorbed with an exclusively anthropocentric valuation perspective. We should therefore welcome this new word, which probably could not have been coined until people went out into space and for the first time saw the Earth from the outside as a whole system rather than as disarticulated parts.

TABLE 1

THE FIVE PARTS OF BIODIVERSITY

COMPONENT	DESCRIPTION
GENETIC VARIATION	(genes in individuals of all living things)
TAXONOMIC VARIATION	(species, genera, families, orders, classes, phyla, kingdoms, and other branches of the tree of life, i.e. the *variety* of organisms)
ECOSYSTEM VARIATION	(the three-dimensional or cubic structures at the Earth's surface (i.e. habitats such as forests, kelp beds, coral reefs) and including the large multi-cellular organisms themselves)
FUNCTIONS OR "ECOLOGICAL SERVICES"	(what organisms and ecosystems do for each other, their immediate community, regional ecosystems and for the ecosphere, i.e. *processes*)
THE "ABIOTIC MATRIX"	(the connected water, soil, sediment, air, and other physical elements within which all organisms evolved)

Biodiversity is inseparable from its encompassing matrix (Table 3). The five components of biodiversity are: genetic diversity, taxonomic diversity, ecosystem diversity, ecological functions, and the encompassing physical matrix. These are outlined in Tables 1, 2, and 3, and discussed below.

GENETIC VARIATION is inseparable from and can only exist meaningfully in individual organisms. It is organisms that contain the units called genes found as DNA and RNA in each living cell. Genetic diversity consists of tens of thousands of different genes in unique combinations in each species. It is expressed through locally adapted individuals and races, physiologically or edaphically unique variants in different parts of each species' natural range, often most evident in marginal populations. Genetic diversity is usually assessed within a single species. The genetic diversity of a particular species would be higher when the species is comprised of many isolated populations (Magurran 1991). Normally, when species (particularly non-migratory ones) occupy large geographical areas, the populations in one part of the entire range differ genetically from populations in other parts of the range and these genetic differences are often adaptive. When one talks of conserving biodiversity, it is well to bear in mind that **whole organisms**, not the genes within them, are the functional entities. This is because only organisms (not genes) can live in real ecosystems. Genetic information within individuals is like a great library of books that was created over a long time. It represents potential opportunities for the evolution of new lineages in future, and potential for better crops, domesticated animals, cures for diseases and biotechnological production of useful substances. It also offers the potential for adaptation to long-term natural and anthropogenic changes in the environment. Loss of genetic variability reduces capacity to adapt to changes.

TAXONOMIC VARIATION consists of the number and variety of species, genera, families, orders, classes, phyla and kingdoms of organisms, present and past. It includes plants, animals, and micro-organisms, arranged (according to modern classification) in five kingdoms (Margulis and Schwartz 1988; Kendrick 1992). The more species an area has, the higher its biodiversity. However, if two areas have equal numbers of species but one has more genera, the latter would have more biodiversity. Canada's taxonomic diversity occurs in many phyla (Appendix 1), although it needs to be stressed that modern methods of research into genetic relationships are bringing about major changes in our understanding of relationships at the phylum level (Margulis and Schwartz 1988). As Appendix 1 reveals, Canada has an estimated 140,000 species, or possibly as many as 280,000 if viruses are included. The majority of species are terrestrial, (Figure 6) while the greatest organic and taxonomic diversity occurs in marine ecosystems. Taxonomic diversity also includes the branching tree of relationships between species and higher groups, which have evolved over the last 3.6 billion years since the beginning of life on Earth.

ECOSYSTEM VARIATION consists of the great variety of three-dimensional (i.e. cubic) systems at the surface of the Earth, including in all cases soils and/or sediments, water, air, and organisms at their interface, with the system energized by the sun (Rowe 1990a, 1990c). Generally, there are no obvious borders between ecosystems, although some (such as shorelines) are more pronounced than others. In a practical way people refer to local and regional forests, grasslands, aspen parkland, wetlands, shallow and deep lakes and rivers, marine kelp areas, and the like as ecosystems. Important in ecosystem diversity are the spatial relationships among all organisms living in a particular area and this includes the plants, animals, and micro-organisms living above ground, in soils/sediment, and underwater. Landscape ecology focuses on changes in ecosystem diversity over larger regions, including all the inputs and outputs from such (cubic) systems and changes over time.

ECOLOGICAL FUNCTIONS OR "ECOSERVICES" of biodiversity are based on a conceptual article by Mosquin (1994) and summarized in Table 2, and further discussed in Chapter 4. Ecological functions comprise the most important aspect of biodiversity. They describe what present-day organisms in all groups **do** for and **to** each other, to help maintain the productivity, health, diversity, harmony and generative powers of their immediate surrounds, for the ecosystems in which they live, and for the ecosphere as a whole. They also describe what organisms have done individually and collectively over the long span of life on Earth going back 3.6 billion years. This means that certain early components of biodiversity provided for the further enrichment of biodiversity and in time for the greater production of different kinds of biological resources and for the long-term productivity, stability, and harmony of the system (the ecosphere) as a whole as we find it today.

An alternate phrase used to denote functions of organisms and ecosystems is "ecosystem services" or "ecological services" as discussed by Ehrlich and Mooney (1983). We must be careful with the word "services", used in today's literature. For example, herbivores did not evolve only in anticipation of providing a service to carnivores. Yet the presence of herbivores can be regarded as a kind of service, since without herbivory, the enormous range of life forms (from microorganisms to large animals) called carnivores, and occurring in all major ecosystems, could not have come to be.

To understand the overarching importance of biodiversity functions, one has to think in terms of evolution over long spans of time. Thus, when a unique process (here called a function) originated in or among organisms sometime in the distant past, this new function made possible the evolution of a novel series of other things or functions (never before present in the geological past). These new functions then became more widespread and "operational", thereby enriching overall biodiversity of the ecosphere. Thus, today, when earlier evolved or "primitive" (supporting) functions are jeopardized, this automatically weakens or eliminates (later evolved) dependent functions. Knowledge of functions should be a fundamental consideration underlying all management of biological resources. Indeed, this knowledge has essential predictive value for management. For example, had the human impacts upon the carnivory function (massive overfishing of fish carnivores) through deliberate overexploitation been taken into account, the Grand Banks fishery would likely not have collapsed.

The ecological functions of biodiversity profoundly affect biological resources, including development, recreation, management, and conservation. It is worth noting that the time scales of these processes are more similar to geology than to biology. They are in the area of "what is happening to the planet? What is happening to the norms of the ecosphere? What is happening to the economy of nature? Increased understanding of the more fundamental values of biodiversity provides the answer to people who ask anthropocentric questions like: "Can wildlife pay for itself?" (e.g. Holdgate 1993), or, "biodiversity should pay for itself". Biodiversity thinking and knowledge provide the deeper, underlying justification behind the importance of protected areas where nature is allowed to survive and evolution to continue.

A total of 21 functions of biodiversity are identified in this report (Table 2). They are summarized below and discussed in some detail in Chapter 4 where examples are provided. These functions are arranged in four groups that reveal a framework of increasing complexity. Seven functions have been placed in the first group, 3 in the second and so on. Reviewers have found that this is a useful and informative way of thinking about the creative forces of biodiversity. It is essential to understand that **all types of individual organisms**, as well as ecosystems, not only do ecosystems have functions and processes. (Appendix 1, Table 2, Chapter 4).

A close examination of the biodiversity

functions framework reveals that the later functions are partially or completely dependent upon the earlier ones. From a functions perspective, we have had a very dynamic situation from the beginning and one which became more and more complex through geological time (as new functions originated). This increasing scale of complexity through time could be considered the law of biodiversity functions. A general rule might state: All biodiversity functions, except primary production, are derived from and dependent upon pre-existing functions. In fact, there is a wealth of direct and inferential evidence suggesting that it may be accurate to claim that it was the functions (and not the mere presence) of species and ecosystems that enabled the ecosphere to become ever more complex, harmonious and beautiful, over its 3.6 billion year existence, a topic now under active investigation (Schneider & Boston 1991).

Biodiversity functions are polyphyletic, meaning that identical or similar functions arose repeatedly in entirely different taxonomic groups of organisms (see Appendix 1) and ecosystems. This suggests that there are consistent, normalizing internal dynamics to the emerging ecosphere as a whole. Or, in other words, innate self-realizing processes must make possible the emergence of parallel

TABLE 2

A FRAMEWORK FOR THE ECOLOGICAL FUNCTIONS OF BIODIVERSITY

A. FUNCTIONS PERFORMED PRIMARILY BY INDIVIDUAL ORGANISMS

1. Primary production (creation of biomass or volume of living matter by photosynthesis)
2. Oxygen production (by oxygen-producing micro-organisms, plants and some animals)
3. Herbivory (protozoa, fungi and animals eating primary producers)
4. Carnivory (protozoa, fungi and animals eating protozoa and animals)
5. Population moderation (a specialized aspect of herbivory & carnivory—diseases, parasitism upon over-abundant species, and "overgrazing" that creates new niches for other species)
6. Nutrient transport (by individual organisms)
7. Sequestering of carbon dioxide

B. FUNCTIONS INVOLVING INTERACTIONS AMONG LOW NUMBERS OF DIFFERENT KINDS OF ORGANISMS

(These functions are carried out because of the co-existence of usually unrelated species in an area, often in immediate proximity, or from time to time.)

8. Seed & spore dispersal (plants); migration (animals)
9. Control of soil erosion
10. Symbiosis (mutually beneficial, intimate, co-evolved associations—extremely widespread and variable in nature)
    a. nitrogen fixation (esp. with bacteria and algae in higher organisms; lichen partnerships)
    b. flower pollination involving insects, birds, etc.
    c. mycorrhiza involving fungi and plant roots
    d. food digestion involving bacteria & fungi in the gut of animals
    e. "fish cleaners" on coral reefs

C. COMPLEX FUNCTIONS INVOLVING INTERACTIONS AMONG LARGE NUMBERS OF DIFFERENT ORGANISMS

(These functions represent an increased level of complexity and some might better be included in 'D' below.)

11. Soil creation and sediment bioturbation
12. Moderation of micro & macroclimate
13. Decomposition (primary & secondary detritivory; including digestion, mineralization of organic compounds, fermentation, etc.)
14. Maintenance of 3-dimensional structures—consequences of multicellularity (trees, shrubs, herbs, kelp, all larger animals, forests, soils; creation of habitat)
15. Communication—both intra- and inter-specific (sight, sound, taste, smell and touch) —via colour, shapes, pheromones, mimicry, camouflage, bioluminescence, radar, etc.

D. ECOSYSTEM FUNCTIONS AND PROCESSES (DEPENDENT UPON MANY OR MOST OF THE ABOVE CONTRIBUTORY FUNCTIONS OF ORGANISMS)

16. Food webs (trophic structure)
17. Biogeochemical nutrient cycling (ecosystem and ecospheric scale)
18. Maintenance of genetic diversity
19. Stability (consequences of disturbances, keystone species, foraging behaviour, species richness, similarity of function, redundancy of function, etc.)
20. Community succession (with or without disturbances)
21. Harmony (a combination of form, movement, structure, and the above functions resulting in a proportionate, orderly, and integral whole (called the ecosphere).

functions in very different taxonomic groups growing in different ecosystems around the world.

The first three functions primary production, herbivory, and carnivory have been extensively studied over many decades in many countries (although not in the name of biodiversity). In Ontario, for example, enormous amounts of public money have gone to subsidizing moose and deer studies, i.e. herbivory of large mammals. Also, the population dynamics and requirements of large carnivores (i.e. the carnivory function) are generally well known, thanks to decades of direct experience and research, although one cannot say this about herbivory and carnivory among micro-organisms where the challenge to seek new scientific understanding is high. Likewise, depending on which group of organisms one is considering, functions such as symbiosis, population moderation, food webs, maintenance of genetic diversity, and others are only marginally or partially understood.

None of the 21 functions or "ecoservices" are mutually exclusive from all the others (i.e. each is dependent on at least one other function).

Ecological functions are usually intricately interlinked with and dependent upon functions and processes of other species in the community. In other words, in a very small way each organism is part of a far larger whole that helps maintain the workings of the ecosphere (defined by Rowe 1990a, 1990b, 1990c and see below). When any species is lost from an area, its functions or services to its ecosystem are also lost; when its abundance changes the effect of its contribution to the overall community also shifts, affecting other species and the whole as a result. For example, the carnivorous sea otters along Canada's west coast were overexploited almost to extinction by hunting. Species of herbivorous sea urchins, unchecked by otter carnivory, multiplied and reduced shoreline kelp forests, causing drastic changes to species dependent upon kelp. The return of sea otters on the west coast is now bringing forth a resurgence of the many ecological functions supported by the great kelp beds.

The orderly and "normal" functioning of very small organisms also determines the abundance of larger, often commercially important species. For example, enormous masses of microscopic bacteria and phytoplankton provide food for zooplankton. All oceanic plankton provide food for krill (sometimes called euphausids in the north Atlantic) and ultimately for fishes, sharks, and sea mammals. On land, a large and varied biomass of interacting soil organisms creates and maintains healthy soils essential for biodiversity of natural ecosystems and for the productivity of crops, rangeland, and forests.

Functions of biodiversity at the level of ecosystem are obviously so complex and intricate as to be enigmatic. Only the functions of the largest whole (i.e. the ecosphere) would be more complex. The relation between ecosystems and biodiversity is explored in a recent symposium volume edited by Shultze and Mooney (1993).

While Table 2 identifies six functions at the ecosystem level, it should be understood that there are different ways of analyzing the workings of ecosystems. One can but dimly visualize the underlying causes of the world that pre-existing biodiversity has created. Analysis is possible, but synthesis and deeper understanding seem to be beyond the human capability even with computers and advanced modelling techniques. In the meantime many of the pieces are being lost. One way of trying to visualize these "higher level" functions is to ask the question: "what functions do wild ecosystems support?" Obviously, all of the functions listed in Table 2 because the workings of individual organisms cannot be excluded. However, there is the implicit recognition that the entire assemblage of co-evolved species in any terrestrial, freshwater, or marine area or region, plus their abiotic context (see Table 3), must be considered *as a system* before the significance of what is being observed can be sensed.

The functions of organisms and ecosystems are also being explored for their role in maintaining the ecosphere as a whole. The notion that the planetary ecosphere is a self-regulating system, first proposed by Lovelock (1979, 1988), is being further explored by scientists and others (Schneider and Boston 1991). The particular functions of biodiversity attracting the attention of researchers are primary production, oxygen production and regulation, sequestering CO_2, moderation of micro- and macroclimate, communication, "stability" (on a global scale = 3.6 billion years of stability), ozone layer creation and maintenance, and some others. These ecospheric functions of biodiversity could be ranked even at a level above ecosystem function (Table 2), since the linkage with geobioclimatic processes is obvious.

THE MATRIX OF BIODIVERSITY. Organisms do not and cannot live separate from the so-called physical environment of the Earth with which they are clearly in some sort of unity. Several key abiotic components: limestone and oxygen, are largely or entirely products of living organisms of the past.

Rowe (1990c, 105) notes that it is inaccurate and misleading to exclude the so-called inorganic or abiotic part of planetary ecosystems from the obviously living organisms. He notes:

> One-eyed biology, lacking depth perception, has misled us into conceiving a world divided into the biotic and abiotic, the organic and inorganic, the animate and the inanimate, the living and the dead. The divisions are false and mischievous. For what would qualify as animate, living, organic and abiotic without sunlight, water, soil, air? These latter components are as vital and as important as the organisms whose life-giving environment they are. The ecosphere, the most perfect ecological system, comprises all-of-them-together.
>
> Endangered organisms per se cannot be preserved. Ecosystems of which organisms are interesting ingredients can, however, be preserved as long as the Ecosphere of which they are parts continues to function in the old, natural and healthy way.
>
> How difficult it is to accept in our hearts and imaginations that the authentic thing, the important thing, the primary reality, is the Ecosphere, one of whose attributes is the phenomenon called life. Life is not a property of organisms, nor of cells, nor of strands of protoplasm, nor of complex molecules like DNA. Life is a property of the skin of the planet and of the ecological systems that the marvellous skin comprises.

Logic dictates that without water there would be no fish, no coral reefs, no kelp and no submergent life forms at all. Indeed, there would be no marine or freshwater ecosystems. Likewise, without air, there could be no flying birds, no air breathing lungs, and without soil the ecosphere would not have the great wealth of functioning organisms that are both shaped by and make the soil. Hence, the definition of biodiversity cannot exclude the context in which living things find themselves. It is for this reason that the definition of biodiversity is erroneously incomplete without recognizing the many aspects of the physical environment with which organisms are essentially at unity. Hence, the fifth or abiotic component of biodiversity (Table 3) needs to be recognized and brought into our thinking, particularly when applying biodiversity knowledge to the management of biological resources.

TABLE 3
BIODIVERSITY'S ESSENTIAL MATRIX

Biodiversity's "abiotic," "non-living", "inorganic" and "inanimate" matrix is inseparable from, enabling, and encapsulating of all organisms, shaping their form, structure, behaviour, communications, life histories, etc. The components of the matrix are:
• water (made possible all aquatic life and determined their forms and other characteristics)
• air (made possible: flying birds, lungs, leaves, communications, etc.)
• soil (made possible: roots, microflora and fauna, etc.)
• sediment (made possible all organisms that live in sediments)
• limestone and other "biotic" rocks (makes mollusc shells, bones, etc.)
• minerals, nutrients (essential for animal blood; plant food)

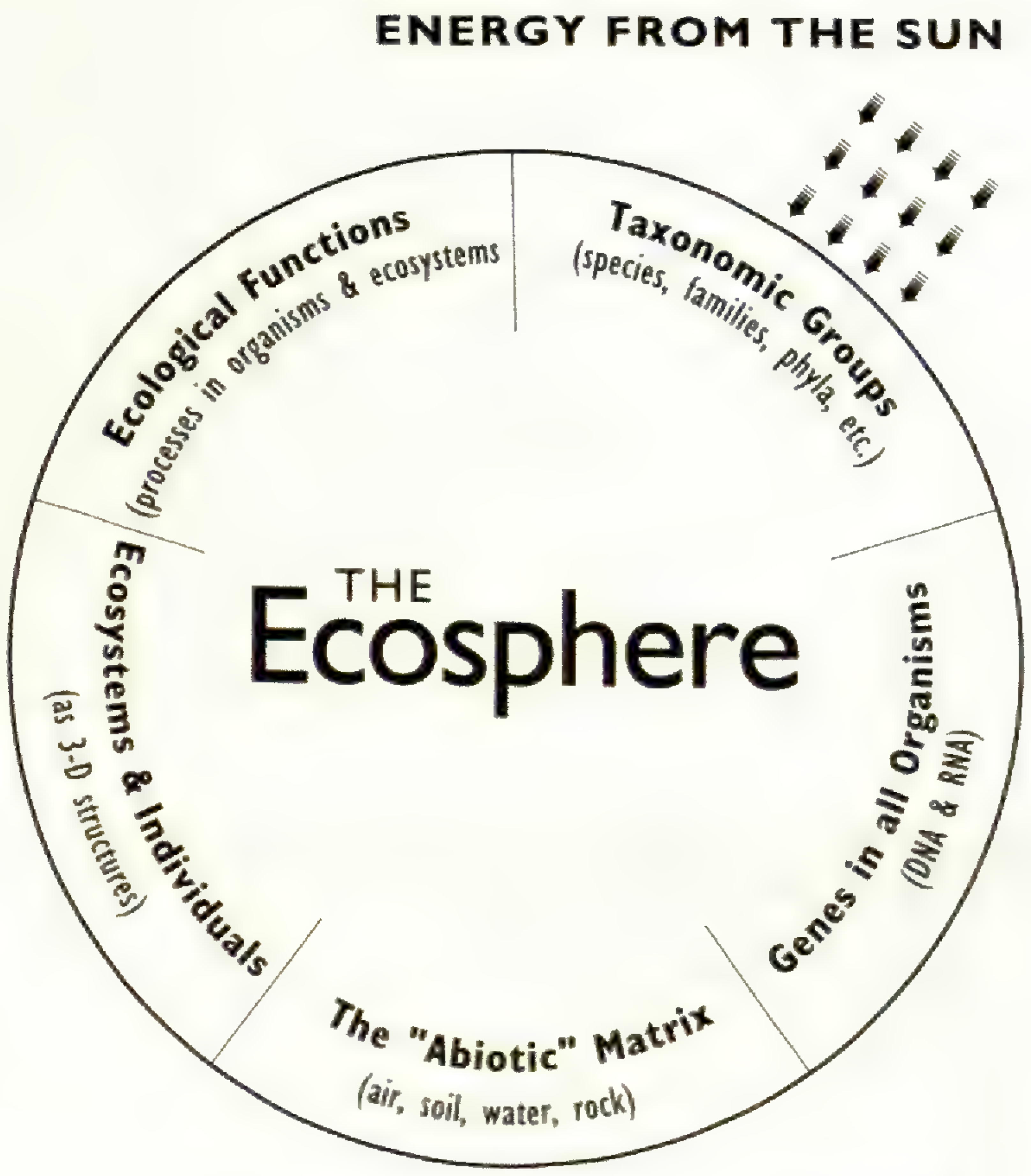


FIGURE 3

The ecosphere, Earth's prime reality, consists of an atmosphere, hydrosphere and lithosphere matrix in which the biosphere is embedded. All living things were created and shaped by the ecosphere, which they in turn helped create.

What the above means is that the larger reality within which a country's biodiversity is domiciled is the planetary ecosphere, whose major subcomponents should be recognized as being inseparable from our thinking about biodiversity conservation. Rowe describes the ecosphere as:

> a thin gaseous stratum resting on liquid and solid strata, with organisms concentrated at the phase boundaries. The gaseous layer is the **atmosphere**, the liquid is the **hydrosphere**, the solid is the soil-and-sediment bearing **lithosphere**. Within this three-way matrix, organisms and their surrounds are often said to comprise the **biosphere** a term apt to mislead by suggesting the pre-eminence of organisms. Actually, all four constituents are essential parts of one homeostatic whole, the **Ecosphere**: literally the **Home-sphere**. This word for the planetary ecosystem has the double advantage of reminding humanity where it is domiciled, while expressing no prejudice in favour of organisms, hence no denigration of earth, water and air as less than organisms, as merely their environment. It implies equal importance among all components while also implying that everything existing within the Ecosphere, including the human race, is a product of it, a subdivision of it, a part of it and therefore less important than it. The Whole Home is the prime reality; all else within is fragmentary, disarticulated, lost and meaningless until conceived and experienced within the context of the **Ecosphere.**
>
> The Ecosphere is realistically conceived as comprising a hierarchy of ecosystems, like boxes within boxes, defined at various scales zonal, regional and local for purposes of contemplation, study, ministration. These sectoral ecosystems simplistically named seas, continents, mountains, plains, deserts, forests, lakes, rivers, settled lands, farm fields, towns, according to prominent natural or cultural features—possess an importance that far transcends their contents (pp. 124-125).

The recognition of the ecosphere and its surpassing importance is further analyzed by Rowe in terms of its ethical significance (Rowe 1990b, 1990c, 1993). The notion of "ecosphere" fills what has, until the 1980s, been a conceptual gap in people's ability to think and talk accurately about the encompassing global environment, its nature, its sectoral ecosystems, the biodiversity within, and humanity's links to the system. The meaning of the ecosphere is difficult for most to sense from the inside. It has been sensed (e.g. by the astronauts) from the outside as the mysterious and seemingly miraculous interconnected whole that it is. The ecosphere seems to be the planet's most important reality, worthy of our highest valuation and respect, and deserving of the highest form of management, namely, leaving it alone and/or restoring it to its stable, creative and normal condition.

2.2 BIOLOGICAL RESOURCES

Resource-oriented agencies and organizations and the media often use the words "biodiversity" and "biological resources" interchangeably. But there are fundamental and practical differences between the two. As noted above, **biodiversity** refers to the overall variety of organisms, their processes, connectedness and matrix, while **biological resources**, on the other hand, has a more restricted meaning. An excellent account of the meaning of biological resources can be found in a major study published by the World Conservation Monitoring Centre in 1992 entitled *Global Biodiversity: Status of the World's Living Resources*.

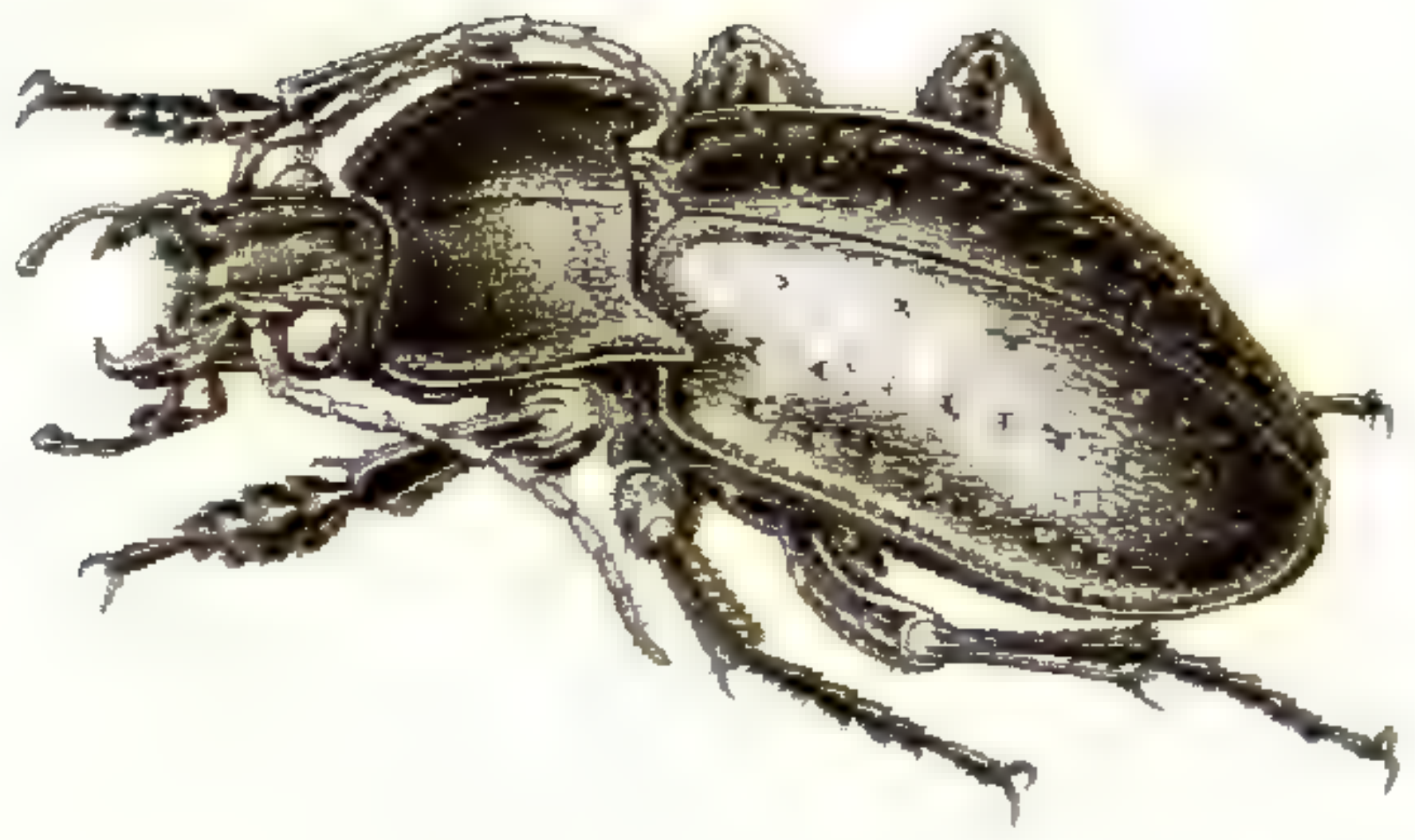
The Convention on Biological Diversity formally recognized the differences when it defined biological resources as "organisms, or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value to humanity". Thus biological resources are used in this report to refer to those populations or stocks of certain species (or of ecosystems) that can be drawn upon to supply a human want or need today or potentially in the future. The notion of resources applies not only to our species, but to all others. The term "resource partitioning" is an ecological concept used to describe the differential use of resources such as food and space by two or more species. Of course, as humans sequester ever more resources required or desired by our species, fewer resources are left for others, hence the accelerating biodiversity crisis world wide.

Biological resources are usually harvested, exploited, or tapped in some way to supply humans with food, shelter, medicine, fuel, and the like. Such resources may be either sold commercially or used for subsistence. It is not known what percentage of Canada's animal, plant, and micro-organism biodiversity represents or provides some kind of resource for human use, but the proportion is very small perhaps one percent of all biodiversity. A criterion that would uniquely identify biological resources is this: is the resource recognized by economists in a nation's traditional national accounts? These accounts are designed to measure commercial and other transactions, and therefore do not represent environmental (or biodiversity) factors that are not captured by such transactions (Statistics Canada 1991b). The economic measuring stick known as Gross Domestic Product (GDP) does not currently take into account the running down, degradation, and depletion of Canada's known biological resources, of which there are some stark examples today, as discussed in Chapter 6 of this report. Indeed, it is a paradox that when fishery, agricultural, or forest resources are depleted, the GDP can actually go up, as was the case with the Exxon Valdez oil spill in Alaska, or the cases of the clearcutting of old growth forests or the large-scale depletion of the cod fishery.

The diversity of species in a given region greatly exceeds the number of resource species drawn upon for human wants and needs. There are over 1,100 species of fishes in the marine, brackish and freshwaters of Canada. But less than 200 of these are commonly sought for commercial or recreational fisheries. Of the 134 native species of trees in Canada (Hosie 1979), fewer than 60 have significant commercial uses in Canada, and some are very marginal.

Then there are dozens of groups of organisms such as jellyfishes, rotifers, protozoans, numerous insect orders, many small marine organisms, unicellular organisms of various types, and phyla of bacteria that have never had any commercial uses or market value at all, hence they are not and cannot (by definition of the Convention on Biological Diversity) be considered as "biological resources". Nevertheless, they may have controlling and determining ecological functions as organisms through their presence and actions in ecosystems (Table 2, Chapter 4). In short, such obscure organisms often underpin the great productivity of many commercially important species. Some economists, however, maintain that these "non-resource" organisms are within the "production function". Of course, some people may acknowledge that human "resource values" are generated in extremely complex and different ways (Chapter 6). Commercial values are most easily reported and easiest to quantify. However, non-commercial values, such as the existence or intrinsic values derived from a valley landscape, a field of wildflowers, a natural prairie, or a solitary butterfly are recognized here as "biological resources" because of the amenity benefits (personal, artistic, intrinsic) they generate for humans. However, these benefits are significantly hard to quantify in the same terms as commercial values, and therefore are omitted in most analyses of resource values.

A growing number of people believe that myriads of other species, which have no conceivable resource value to humans, have an intrinsic right to survival. The World Charter for Nature (United Nations 1982) and the Convention on Biological Diversity (1992) recognize such rights of all species to survive. As well, there is an emerging recognition that the largely unsensed value of biodiversity as such lies in what these "non-resource" species and ecosystems do for the health of rivers, lakes, soils, marine areas, and for living organisms. A growing number of people and nations recognize that biological resources should be developed or used in an ecologically sustainable fashion, since failure to do so has repeatedly undermined the abundance of economically important species and what is sometimes called the "ecological security" of the planetary ecosphere.



CHAPTER 3

STANDARDS/NORMS FOR BIODIVERSITY

To assess the status of a country's biodiversity, a baseline norm or standard is essential. We take the consequences of long-term evolution as the norm but interrupted in eons past by at least several large comets colliding with the Earth. Hence, the most appropriate biodiversity standard for any area on Earth is the relatively "wild" and "uncontaminated" condition of ecosystems and their organisms that would now be present had major human influences not modified or eliminated the geologically "normal" biodiversity in the area or region. We know generally about the history of norms of the planetary ecosphere through the study of geography, geology, palaeontology, ecology, and evolution. "Normal" in this sense means that over eons of time there have evolved baselines defining the natural order in which biodiversity thrives in any part of this planet.

Of course, over the past five thousand years, human intelligence has become part of the natural order. The unprecedented power of our individual and collective intelligence is uniquely responsible for the great changes (mainly extinctions, extirpations and toxifications of wild species and natural ecosystems) that are depleting the planet's evolved biodiversity standards or norms. However, while the "norms of Earth" did indeed give rise to humans through the operations of natural processes, the deliberate or unconscious destruction of a rich biodiversity in vast regions of the planetary surface and within an extremely short time scale (i.e. only hundreds of years) appears to be an aberrant deviation from the norm. It is a deviation because when it happened in the past (end of the Permian; end of the Cretaceous), vast legions of life forms vanished forever. Hence, we agree with Berry (*in* Meeker-Lowry 1988) that "the integral functioning of the natural world is the supreme model of managerial success". This is the fundamental case for us humans to do everything within our power to retain the norms of Earth at almost any (temporary) hardship or cost. This should mean: no more losses of existing biodiversity (and all the functions that organisms and ecosystems perform), major deliberate rollbacks of the most destructive anti-biodiversity activities of humans, namely agriculture, industrial forestry, industrial fishing, and the reversal of the (legally sanctioned) toxification of the world. Some ways to seek the achievement of these normalizing goals are presented in the final chapter.

For most of Canada, we have accepted the mid-18th century (1750) as the standard or norm against which deviations are to be judged or measured. At that time the land and seascapes of Canada were relatively undisturbed by industrial society. While in pre-industrial society people had been present for thousands of years, their impacts on "biodiversity norms" were relatively slight. Adequate historical and scientific records are available for drawing conclusions about the state of biodiversity at that time, although it is recognized that many local sites (now totally converted to other uses) may have had specialized ecosystems and it would not be possible to determine their earlier, more "normal" state. A sufficient amount is also known based on sediment core analyses (Warwick 1980) to provide a sound basis for setting this time as a baseline for comparison.

When considering norms, it is essential to know that it is never possible to recreate a species or restore an ecosystem to some past condition. Organisms are extremely conservative, however, and when given an opportunity to recolonize the lands or waters of a particular place, most will do so at the appropriate time, assuming that ecological conditions are not drastically different than they were prior to elimination of the norm at the site. As is well known, the presence of changed circumstances (exotic species, drainage, loss of organic material, toxics, fertilizers, etc.) can make profound differences as to the kind of ecosystem that will emerge at a site over time. But generally speaking, in Canada, we can, if this is the will of management and public policy, assist almost any ecosystem to undergo succession in the direction of its norm, assuming the species can be available for colonization and that sufficient time is permitted. Depending on the ecosystem, the time required for restoration to a "near normal" state would vary. Thus, a marsh ecosystem can be re-created in a matter of decades, while bogs, fens or temperate rain forests will take thousands of years.

The standard is also determined by a number of known trends that produced today's biodiversity over long spans of geological time. These are:

- from "simple" life forms to ever more complex biological organization;
- from few ecological functions to many (Table 2; Chapter 4);
- from simple ecosystems to ever more complex, three-dimensional ones;
- from few senses to more complex senses;
- from a highly toxic primal ecosphere to

> a progressively less toxic one that became ever more suitable and conducive to the evolution of diverse life forms from pre-existing biodiversity (Environment Canada 1991c, Chapter 1, p. 9)

In Canada, following the mid-18th century, we saw the beginning of historic transformations of major ecosystems by colonizing Europeans, a process that is continuing today in places such as the Grand Banks of Newfoundland, Clayoquot Sound, James/Hudson Bay river basins, urban areas, and the like. Obviously, a great deal of direct evidence of the details of Canada's biodiversity in 1750 has vanished. But it does not take a trained ecologist or geographer to enable one to draw fairly sound conclusions about its general condition nearly 250 years ago.

To summarize, biodiversity norms for any part of the planetary surface are ones that comprise our best understanding of the "natural" condition in the sense that they have **stood the test of time**. The norm thus defined recognizes that the known ecologically sustainable state is that of natural ecosystems or what many call wilderness. Thus, any description of the "state of biodiversity" must describe deviations from this norm, and address the question of "how much deviation should be of serious concern or even dangerous? The scale or intensity of deviation is a prime consideration in drawing conclusions about the right and wrong of management decisions and policy. The essential and operational questions would be: how much conversion of native prairie to agricultural monoculture is enough? How much clearcutting in B.C. is enough? How much pollution of the Great Lakes is too much? How much overexploitation of the Grand Banks is too much? What would constitute excessive cumulative effects of hydroelectric dams in the three provinces surrounding Hudson Bay? How many people is enough for the planetary norms to sustain?

In answering these questions, much more than biodiversity values/functions are at stake since the destruction or collapse of norms locally, regionally or even globally can have major impacts upon the economies (i.e. the efficiencies and success of natural systems in creating and maintaining the ecosphere) of nature and humans alike. Numerous graphic examples of unsustainable assaults against planetary norms abound around the world. The norms retreat or vanish; ancient balances are destabilized or lost. Practical experience and observations indicate that the retention of these "natural norms" is the equivalent of providing, indefinitely, for a secure and ecologically sustainable future. While other norms (which eliminate natural systems) are possible to conceive, (for example, ones based upon genetically modified organisms and/or on blind application of the state of technological know-how), there can be no way of testing their sustainability.

3.1 GENETIC NORMS

Each individual species is unique and has its own standard or norm for genetic diversity at a moment in time within its ecosystem. Assuming that the standard were defined, deviations from this norm could presumably be discovered and measured. Deviations would include significant new human-caused mutations or gene combinations, loss of genes, pressures of habitat fragmentation, significant changes in gene frequency in a population or the extirpation of genetically unique populations. Techniques for directly measuring and monitoring changes in genetic variation are reviewed by a number of authors (Lande and Barrowclough 1987; Brown et al. 1989; Hillis and Moritz 1990). These techniques include karyotypic analysis, electrophoresis, DNA sequencing and hybridization, sibling analysis, mt(mitochondrial) DNA comparisons, morphological and physiological comparisons (within populations and between geographically separated populations, including endemics), offspring-parent regression, and practical "hands on" experience from many decades of plant breeding using material collected in the wild.

While the above techniques are available, they are prohibitively expensive to apply to Canada's wild species. Hence, there is a considerable shortage of research data on genetic variations and adaptations in Canada's known wild species, which makes it impossible to track changes or trends in genetic variation and to draw conclusions about losses or gains of genes. About all we can do in Canada is use inference to determine deviations from historic norms or to determine which geographic regions might constitute genetic hotspots and therefore be more worthy of conservation efforts.

Biogeographers now know which regions or ecosystems of Canada harbour more phyla, classes, orders, families, genera and species. It is our view that such biodiversity hotspots would also harbour more genetic variation within the species present. Conversely, in areas that have low taxonomic diversity, genetic diversity is expected to be correspondingly low. While we know of no recent scientific review documenting such a relationship, its validity appears to be logical and probable on the basis of knowledge of genetics and taxonomy. An older study (Vavilov 1949/50) described such a relationship for many cultivated plants and particularly for those whose wild relatives were still extant in parts of north Africa and the Middle East — wheat, oats, barley, and others (Vavilov 1949/50; Barrett 1993). It seems reasonable, therefore, to draw the conclusion that large-scale conversions of natural ecosystems to monocultures in southern Canada results in far greater losses of unique gene diversity than in more northern areas.

Inference about genetic variation can be applied in another way. We know that plant species in particular vary enormously with respect to the sum total of genes, with some species being highly homozygous, others heterozygous (Barrett & Kohn 1990). A specific concern in Canada would be the loss of unique "hardy" genes in marginal populations adapted to survive at the extreme limits of species' ranges (Mosquin 1971a; Scudder 1989; 1993). There are literally thousands of Canadian species in dozens of phyla that contain populations at the northern fringes of range for the species. This is particularly true for species having their principal ranges in the United States. Parts of southern Canada where many such populations occur in the northern extremities of their ranges include: southern Vancouver Island and the Gulf Islands, the dry valleys of southern B.C., the southern Canadian prairies, southern Ontario, and southern Nova Scotia and New Brunswick. Likewise, many arctic tundra and arctic/subarctic marine species reach their southern limits in boreal parts of Canada.

There is no reason to believe that at genetic levels of variation the overwhelming majority of these marginal populations are not; in one way or another, adaptively distinct. Adaptation in marine ecosystems should be similar, particularly in non-migratory species. Thus, northernmost populations of marine species in both the Atlantic (such as the Atlantic cod) and Pacific coasts of Canada may be expected to be adaptively unique. Such marginal populations, once eliminated through overharvesting, may be impossible to restore, even over the long term.

Abnormal mutation pressures can also bring about deviations from the genetic norms in an area or place. This can happen when species or populations are exposed to certain anthropogenic factors. Human-caused deviations from what would otherwise be the norm include mutations caused by radionuclides (caused by nuclear accidents, dumping of nuclear waste, radioactive mine slag heaps), ultraviolet radiation (caused by destruction of the ozone layer), mutagenic chemicals (caused by pollution from factories, cars, municipal dumps, etc.) and elevated temperatures (near sources of high heat). Abnormal environments increase the number of mutations above the normal background level. While such mutations increase genetic diversity, most are known by geneticists to have a negative effect on the organism (i.e. they are inadaptive), as they disturb the genetic balance resulting from thousands of years of selection. Exotic genes may enter genomes of native species through hybridization with introduced exotic stocks and species. These also may perturb natural genetic harmonies. In these two cases, higher genetic diversity does not equate with enhanced biodiversity as it is a departure from our A.D. 1750 baseline.

A specific example of human-caused mutations in natural populations that have created "unnatural" or abnormal variants (deviations from the norm) is that reported by Shaklette (1962, 1964), who described cases where a diversity of mutant clones of *Epilobium angustifolium* and *Vaccinium uliginosum* originated on radioactive pitchblende deposits at Port Radium, N.W.T. within a few metres of the usual variants. About 185 million tonnes of ore have been produced from Canada's uranium mines

(Environment Canada 1991b). Thus, human-made local habitat can cause the formation of new local variants, which would constitute deviations from the genetic norm for these species in the area.

3.2 NORMS FOR SPECIES, GENERA AND OTHER TAXA

The standard for taxonomic diversity is based on a different criterion from that of genetic diversity. The only practical standard possible is the *numbers of taxa* (species, genera, families, etc.) present in an area or region at and before the European colonization of the country. The norm would include native species as opposed to the introduced or exotic ones. Proportions of native species lost should be measured against the size of the "original" indigenous fauna and flora.

However, many exotic species of plants and animals are firmly established, and while they were not part of the norm of 1750, they would be difficult or impossible to eliminate and hence their presence cannot be ignored in any census of taxonomic biodiversity. Their initial effect may be to increase taxonomic diversity. In the long term, exotic species may decrease native biodiversity by displacing other species, reducing populations, species, higher taxa, and diminishing ecosystems. A glance at exotic species listed in Table 5 indicates that the deviations from taxonomic norms in many parts of Canada are widespread with major losses of native species and, as a consequence, significant changes to natural ecosystems.

In a practical sense, we already know that changes in ecosystem diversity have been infinitely greater (and much more profound in their social and economic importance) than changes in numbers of taxa that have resulted from these ecosystem conversions. For example, while most of the "Carolinian Forest" of southern Ontario has been eliminated, the majority of species originally present are still found locally in isolated fragments of their former range (Oldham 1983), although some are now rare. But most smaller areas of southern Ontario, which are occupied by farms and other developments, are certainly less diverse taxonomically. Hence the question of scale is important in measuring loss of taxonomic biodiversity. Similarly, while some of the genetic variants of most species adapted to these clay soils have almost certainly vanished in the area of the former "Regina prairie", the many native species (i.e. taxonomic diversity) formerly colonizing the prairie are still present in the province. They are, however, greatly fragmented and reduced in numbers and completely extirpated in large areas. To cite yet another example, logging practices across Canada have drastically altered the "normal" flora and fauna over extensive regions of the country. Yet, the taxonomic diversity on the larger scale remains, although it has been altered in terms of the relative abundance and evenness of distribution of native species in local and regional ecosystems. Modifications are also caused by local extirpations while population explosions of some species, for example, fireweed, *Epilobium angustifolium*, are common following logging and burning of clearcuts in B.C.

The taxonomic approach to measuring the status of biodiversity is basically a "phyletic" one, since it can compare changes in diversity of taxa at various phylogenetic levels over time, assuming that the number of taxa in the many groups we have in Canada is actually known. For most groups (e.g. microflora and fauna), the necessary baseline inventories and taxonomic studies have not been undertaken. While the status of taxonomic diversity may well be subject to quantitative description, the problem with simply tallying up numbers is that there are so many unknowns. For example:

1. widely distributed plant and animal species have a strong propensity to survive in a threatened or even endangered

state in small fragmented populations provided that their parental ecosystems are still present. The well-established area/species rule (Figure 12) dictates that a 10-fold decrease in area of habitat halves the number of species, suggesting that taxonomic losses on the large scale are occurring unnoticed or unrecorded. For example, in the case of lichens in the Carolinian zone of Canada (Chapter 5), major losses of species are being documented. For other groups, changes in taxonomic diversity could not be deduced from an analysisof available monographs and other treatises;

2. there are an estimated 140,000 non-viral species in Canada (Appendix 1). For many taxonomic groups, museum collections are still being built, new species are being described, and extensions to geographical range are being documented. Where older collections are lacking or taxonomic research is not taking place, it is not possible to document the extirpation or extinction of populations and species. Hence, we have devised a method for estimating these losses, based on the proportion of losses in better studied groups; and
3. in a country as big as Canada, extinctions and regional extirpations of lesser-known taxa are usually impossible to demonstrate because of the lack of adequate baseline fieldwork or follow-up surveys. New records are sometimes found of species that were thought to be extremely rare. Taxonomic resources are currently too limited to explore all suitable habitats in search of a particular species.

Because of the incompleteness of taxonomic studies and biological inventories in Canada, we could not use direct evidence of species losses to determine deviations from the pre-defined 1750 norm as accepted herein (with regard to native taxa for Canada's overall species diversity). A new approach has been taken in this study to estimate species losses in all groups since approximately 1750. This involves:

1. preparing a complete census of numbers of known (described) species in all groups (excluding naturalized exotics), and then estimating the number of indigenous species not yet described by taxonomists;
2. identifying well-known taxonomic groups for which information is available on historical and recent trends and calculating the portion that is vulnerable, threatened, endangered, extirpated, or extinct in a province or the country as a whole;
3. using the proportion from 2) estimating the number of species at risk in all groups; and
4. noting groups for whose survival causes serious concern and discussing the causes of their decline.

In other words, taxonomic norms for Canada are arrived at retroactively, by drawing conclusions and making extrapolations based upon the few better known groups of rare, vulnerable, threatened, and endangered species and populations whose status has been determined by criteria of the Committee on the Status of Endangered Species in Canada (COSEWIC) and some other studies (Section 5.2).

Both decreases and increases from normal taxonomic diversity in an area can be damaging to normal biodiversity. This is well-recognized today by increasing numbers of managers who are beginning to talk about "managing on an ecosystem basis", which simply means manipulating species and habitats so as to point the area under management toward its normal species composition and ecosystem structure, while recognizing that one can only manage in a forward direction. Some foresters have maintained that mere increases in biodiversity are a good thing. For example when forested areas are clearcut into patches, new species can move into cleared areas and the "edge effect" of ecotones between cut and uncut areas can result in the influx of additional species. However, such fragmentation of a forest can result in increases in predation upon woodland nesting birds by crows, grackles, jays, raccoons, and also increased nest parasitism by cowbirds, meaning that this kind of increase in taxonomic biodiversity can be a negative factor in the ecosystem. Likewise, the introduction of exotic weeds in disturbed or altered ecosystems may initially increase the total number of species. However, such increases must be classified as negatives, and undesirable because of the ultimate decrease in numbers of native species and other taxa.

3.3 ECOSYSTEM NORMS

There can be only one true standard or "normality" for ecosystem diversity that determines the yardstick against which deviations from norms can be measured and assessed. The standard has been set by the natural processes of the ecosphere operating over vast spans of time, but recently disrupted over enormous regions by human activities. In simple terminology, no one can deny that native prairie, old growth forests, untrawled ocean floors, clean water in lakes and rivers, soils with their natural microflora and fauna, organisms uncontaminated with toxic synthetic chemicals, heavy metals, human-produced radionuclides, and clean air are the constituents of normal ecosystems of this planet's ecosphere. These elements of ecosystems should be seen for what they are: the norms of Earth. The notion of ecosystem norms recognizes and includes a certain level of perturbations'such as fires in forests or grassland (White and Pengally 1992), effects of storms, the abundance cycles of many herbivores and carnivores, diseases or starvation of over-abundant species, and other natural trends, cycles and disturbances. All species require a place to live and thrive in a portion of the ecosphere in the forms of space, foraging territory, migration routes, food, etc. Similarly, small areas for living, raising crops, and for movement by humans do not threaten the norm. The deviations from the norm are serious only when they are at a scale and consciously carried out so as to alter and eliminate ecosystems over extensive areas. Again, a key management question is: how much destruction of planetary norms is too much?

Deviations from ecosystem norms are easy to observe directly, particularly in terrestrial parts of Canadian ecosystems. An airline flight over the Canadian landscape brings home the enormity of ecosystem changes in many parts of southern Canada, and across the boreal forest. In southern Alberta, Saskatchewan, and Manitoba, huge areas of monocultured crops have replaced formerly diverse grasslands. Millions of hectares of Canada's forest have been clear-cut and such clearcutting is being extended into new and more marginal areas. The "clearcutting" of offshore banks by industrial trawling fishing gear is less evident, but nonetheless present and intense.

In our view, survival of ancient ecosystem norms over large regions is a prerequisite for a healthy and safe home for our species and all others into the foreseeable future. Hence, normal (i.e. wild, natural, etc.) ecosystems and their species need to survive in dominating abundance across the landscapes of the nation (see Chapter 7). In every significant ecological unit of the country, more area needs to be natural than modified or converted to human uses. But the seemingly inexorable trend today is toward ever greater destruction, transformation and loss, aided and abetted by official government policies and programs. The above "geological time" view of the deeper value of natural ecosystems implies that people must come to understand why they exist solely for the sake of the world and not the other way around.

3.4 FUNCTION NORMS, OR "ECOSERVICES" OF ORGANISMS AND ECOSYSTEMS

Loss of functions or services (Table 2) comes about when the organisms or ecosystems providing them become eliminated or replaced by different organisms. To judge the significance of these deviations would require valuation criteria and a sound knowledge of the ecological functions of species and ecosystems of the area under consideration. We are not aware of any cases where managers of forests, fisheries, agriculture, or land developers have ever carried out such analyses. But simple observations reveal that great changes in functions have taken place over extensive regions.

To grasp the significance of function norms is to gain an insight into the importance of maintaining biodiversity. Norms can be maintained through taking management steps that ensure that the micro-organisms, plants, animals and ecosystems that carry out these functions can survive in natural systems in abundance into the future as they have in the past.

Like the evolution of species and ecosystems, the origination of functions is best considered on a geological scale of time. Thus, it is worth re-emphasizing that the origination or evolution of millions of life forms on our planet would never have been possible had pre-existing life forms not been able to "discover" new functions, which then made new norms possible. A few examples will suffice: without trees, woodpeckers and canopy-requiring birds and insects would simply not have evolved. Shade tolerant deep forest plants could not evolve without forests. Pollinating bees would never have come into existence without a long co-evolution with flowers. Wood boring insects that feed a variety of birds would not exist, and so on for species and structures of major ecosystems. When visualized in these geological scale terms, one senses that the biodiversity around us is intensely interactive, co-operative, and harmonious in its full expression, and the continuing massive losses of its parts could be a harbinger of great instability, insecurity, social breakdown and misery for humankind in the very near future as human numbers continue to escalate.

3.5 NORMS OF THE ABIOTIC MATRIX

As noted earlier, the abiotic matrix within which biota are embedded has profoundly determined the form, structure, and function of biodiversity. It is because of air that we have birds; water has made fish possible, air made lungs possible, and so forth. For millions of years the abiotic matrix of the ecosphere has been self-cleansing, becoming less toxic and more benign to life. Heavy metals were slowly sequestered away in sediments. Living things themselves participate in this purification process (for example, oxygen formation, mineralization by bacteria, etc.). These "normative" ecospheric processes have now been reversed by industrial societies with catastrophic effects upon embedded biodiversity and its functions. The two main sources of alien toxics are heavy metals ("unnatural resources") brought to the living surface by the mining industry, and synthetic chemicals of the chemical industry. You can see their presence by looking at red sunrises and sunsets, or examining government statistics. Overfertilization of lands and waters by agriculture, lawns and golf courses, toxification of rivers, air and soils by industry, and large-scale pollution of air and water by municipalities, must be seen for what they are — deviations from the planetary norm.

Two of our federal agencies, Statistics Canada (1991b) and Environment Canada (1991c), have published excellent charts, graphs, histograms, etc. which show numbers directly related to our understanding of the causes of many trends in certain components of biodiversity, and which demonstrate how the abiotic environment is being changed by human activities. Environment

Canada (1991b) also published *A National Set of Environmental Indicators*. In these documents we find detailed statistics on:

- global production of CFCs
- global carbon dioxide emissions
- ocean dumping permits issued in Canada
- estimates of the severity of soil toxification, compaction, and erosion on agricultural lands
- effluents from pulp and paper mills
- heavy metal emissions in Canada — for arsenic, cadmium, mercury, copper, chromium,
- manganese, nickel, and antimony
- oil spills reported in Canada
- trends in emissions of nitrogen oxides and sulphur dioxide 1955-1985
- examples of toxic, synthetic organic compounds and their known health effects
- commercial agricultural fertilizer application by sub-basin 1980-1985
- agricultural pesticide expenditures and densities by sub-basin

Dozens of other abiotic factors are also being regularly monitored. When looking at this sort of abiotic data, we must remember that biodiversity becomes embedded in these alien substances. This abiotic matrix is becoming toxic to biota over ever larger regions and is responsible for the loss of frogs, lichens, mychorrhizal and other symbiotic functions, 60,000 essentially lifeless lakes in Ontario and Quebec, vanishing butterflies, and so on.

Recently, the International Joint Commission (IJC 1994) released its annual report on chemicals in the Great Lakes, which reported that a wide range of synthetic toxics (which are still legally produced in Canada and the United States) are present and impacting on the growth, reproductive and hormonal systems of people and lake biota alike. The IJC recommends that governments adopt a preventive strategy to ensure that persistent toxics are not created in the first place.

The very idea that the Earth's ancient norms or standards are worthy of protection and restoration is perfectly radical, for the idea is at the unsensed root of our evolutionary history and that of millions of other species. These norms, these standards are what caused all-of-us-together and the ecosphere in which we live to have come to be.

CHAPTER 4

ANALYSIS OF ECOLOGICAL FUNCTIONS

As outlined in the previous chapters, biodiversity includes much more than genes, taxonomic groups, and ecosystems. There are also the overarching and controlling functions (Table 2), or what are sometimes referred to as "ecoservices" of organisms and ecosystems. The many things that individual organisms, larger groupings of organisms, and ecosystems do and which affect their immediate surrounds, associated organisms, local ecosystems, and ultimately the planetary ecosphere as a whole, are what make up the functions or services of biodiversity.

Biodiversity functions of organisms and ecosystems have worked to create the natural diversity, productivity, health, evolution, balances, and harmony of the planetary ecosphere and its parts. Knowledge of functions tells us how (and sometimes why) ecosystems work as they do, and much of this knowledge has predictive value to resource management. In this century at least, knowledge of the workings of some functions discussed here has had a major positive effect upon the enlightened management of biological resource species.

The notion of functions, or ecoservices, is not to imply that the activities of biota are directed or goal-oriented, or that collectively the activities form a vast co-operative enterprise such as has been suggested by some advocates of the Gaia hypothesis (Lovelock 1979, 1988; Goldsmith 1990; Schneider and Boston 1991). Each era of life adapts to, and depends on, the ecospheric condition created by the preceding era. Evolving species and ecosystems modify conditions, requiring organisms in subsequent eras to adapt to (or avoid) those changed conditions. Thus, the first photosynthetic organisms created conditions for aerobic (oxygen-using) life forms. To these primitive "plants", oxygen was a by-product, while serving as a useful basis for metabolism of subsequent oxygen-breathing species—an ecoservice. These functions are identified and presented here as observed phenomena that are describable, but not necessarily explainable by science—at least not at a deeper causal level. But they need to be reviewed carefully when contemplating the meaning of biodiversity conservation and the development of strategies and action plans for the long-term management of any region or country.

Some functions are truly ancient, having taken hundreds of millions of years to evolve;

others are relatively recent in origin. Many (possibly most) are intimately co-evolved. All have become integral parts of the Earth's generative, stable ecosphere. Certain functions are duplicated by many species (primary production); others can be carried out by only a few groups of organisms (nitrogen fixation).

None of the defined functions are mutually exclusive and the more complex functions require most of the others. Some are intricately interlinked, being as they are, different aspects of some larger encompassing function. For example, when oxygen is created by photosynthesis, we also have primary production: the fixation of carbon and the production of fuel for food and decomposition. But the fixation of carbon takes place in other ways as well (4.7 below). A study of the framework provided in Table 2 reveals some of the more obvious linkages among the 21 listed functions. In the final analysis, and as noted earlier in this report (Table 3), one cannot draw a clear distinction between "biotic and abiotic" or "organic and inorganic", as is so frequently done in biology textbooks and the media. The concept of overall connectedness merits wide study and thought. Recent papers in this field by Rowe (1990a, 1990c) provide a focus for this emerging area of awareness and its generally unsensed significance. The sequence of functions discussed below has been outlined in Table 2.

4.1 PRIMARY PRODUCTION

Primary production is the capture of energy from sunlight by plants, certain common bacteria, and many proctists (algae) that produces an enormous array of organic matter—carbohydrates, proteins, and other compounds. Primary production can be measured by determining the number of grams of carbon that is converted into gross living biomass in any area by all primary producers present, for example, five grams of carbon per square metre per unit time. All herbivores and carnivores, from the protozoa to vertebrates, are totally dependent upon primary producers in all ecosystems. Primary production is first and foremost the most important function of biodiversity. The nature, amount, and variety of primary production in any ecosystem has always been the key determinant of the evolution and diversity of all animal life. The products of primary production are not the volume of biomass alone. Rather, the products are incredibly diverse—from microscopic forms, to kelp, herbs, and trees, which provide food and habitat for all the world's dependent herbivores and carnivores in all ecosystems.

As Canada is a large and diverse country, the particular mix of primary producers varies enormously from one ecosystem to the next. In terrestrial ecosystems it is primarily the function of plants; in marine ecosystems it is the function of photosynthetic bacteria, algae, and sea grasses. In terrestrial ecosystems (prairies, valleys of southern B.C., southern Ontario, farmed areas of the maritimes) the mix of primary producers has changed fundamentally as a result of the economic and recreational activities of people. In many regions diverse assemblages of natural primary producers (and dependent herbivores) have been replaced by simplified assemblages of primary producers or by monoculture fields of grain, which have an entirely different set of dependent herbivores and carnivores, (i.e. domestic stock and people). However, while biodiversity has been variously affected in such regions, the pure function of primary production may sometimes be as high or higher than was present in the wild state (using 1750 as the baseline), with the difference being that almost all net benefits of primary production of such regions are being channelled into people.

Many specific effects of people upon primary production can be reviewed. For example, one factor in reducing primary production in natural forest ecosystems is the impairment of the functions of fungi in soils by agricultural/forest practices and/or atmospheric fallout (Hawksworth 1991a, 1992). Hawksworth notes that fungi are critical components of both mycorrhizae and lichens, and that up to 80% of the world's seed or vascular plants are probably mycorrhizal. As well, primary production is greatly increased by the below-ground fungal networks performing vital roles in the absorption and transport of soil nutrients (4.6 below). In return, fungi receive some of their required carbohydrates from the plants with which they are so intimately associated. Loss of humus, which moderates moisture content in soils, may cause a reduction in primary production.

Primary production in boreal and tundra ecosystems is also thought to be greatly enhanced by the fixation of nitrogenous compounds by lichens (Hawksworth 1990, 1991a). The fixation is a function of the cyanobacterial or algal partner of these lichens which are widely distributed and abundant across the breadth of Canada's boreal and tundra regions.

Primary production is carried out by some bacterial phyla, all proctist algal phyla, lichens, mosses, lycopods, horsetails, ferns, conifers, and flowering plants.

4.2 OXYGEN PRODUCTION

In the long history of life on Earth, one of the first determining functions of biodiversity was the production of free oxygen by micro-organisms. Oxygen production was a necessary prerequisite for the existence of any animal life and indeed for the very safety and security of the ecosphere as a whole. Free oxygen in the atmosphere, water, and soils has been incrementally generated over billions of years, first by photosynthetic bacteria, then by algae, and eventually by plants. Photosynthetic bacteria still occur in great abundance in the upper waters of some parts of the world's oceans (Holland 1984; Lovelock 1988). These bacteria are one of today's principal sources of atmospheric and oceanic oxygen.

The presence of significant amounts of atmospheric oxygen is also a prerequisite for the natural formation of ozone, the shield of atmospheric gas that has formed over eons of time and that now protects the planet's plant and animal life from being damaged by lethal levels of ultra-violet radiation emanating from the thermo-nuclear fires of the sun. Ozone is a form of oxygen containing three atoms instead of the normal two, and has the capacity of absorbing the sun's ultraviolet rays, preventing them from reaching the surface of the planet. The linkage between the biodiversity function of oxygen production and the existence of the ozone shield is being explored by scientists examining the validity of the idea that the ecosphere is a self-regulating mechanism (i.e. the Gaia thesis: Schneider and Boston 1991). The ozone itself is being thinned and reduced as a result of ongoing production and release of enormous amounts of ozone-destroying chemicals (Environment Canada 1991c). At the same time, there is evidence that cyanobacteria themselves are being reduced in numbers by additional ultraviolet radiation entering the ocean surface through the thinning ozone layer (Cullen *et al.* 1992).

While the framework for biodiversity functions outlined in this report (Table 2) does not specifically consider ozone production as a biodiversity function, it should be apparent to the reader that without oxygen, the ozone protective shield could never have developed. Thus, it was the biodiversity function of oxygen production that made it possible for the ecosphere to gradually shield emerging life from the deadly effects of the sun's ultraviolet rays. Over the past half dozen years reports have indicated that ozone thinning above Canada is continuing (while at least one Canadian corporation continues to freely produce and distribute large volumes of ozone-destroying chlorinated fluorocarbons with the full approval of our national government).

Oxygen production is carried out by all primary producers; these are listed in section 4.1 above.

4.3 HERBIVORY

Herbivory is the function of animals eating primary producers. It is central to all food chains in all ecosystems. Among microorganisms, the protozoa "graze" on bacteria, while zooplankton and other invertebrates feed on algae and plants, as do a wide range of herbivorous vertebrates.

The function of herbivory is what provided the basis for the evolution of all animal life, for if the ecosphere's primary producers were not edible, carnivores could not have evolved. Canada's major herbivore groups are detailed in Appendix 1. Many of Canada's larger mammals (elk, bison, deer, mountain goat, moose, sheep, caribou) are entirely herbivorous; some are omnivorous (bears, red squirrels, raccoons), while many are mainly or wholly carnivorous. Populations of these larger herbivores are usually monitored and managed by government agencies and hence, knowledge of their status is usually available. However, some herbivores are sensitive to major habitat alterations, as for example the woodland caribou, a species that has seen major declines in the southern limits of its range. Many smaller mammals are herbivores (grey squirrels, mice, kangaroo rats, snowshoe hares, woodchucks, ground squirrels and others).

As well, herbivorous insect larvae and adults are extremely abundant in Canada's forests, grasslands, and tundra. These include pollinators such as bees, flowerflies, some wasps, and the like. Herbivorous insects form the essential food for the majority of perching birds as well as for many carnivorous insects. Many waterfowl species are primarily herbivores, although some are omnivores. In the oceans, zooplankton and sessile filter feeders are the primary herbivores (filter feeding on phytoplankton), while a variety of marine animals from sea urchins to fishes consume seaweeds.

From a biodiversity functions perspective, plant parasites, which are common in several plant families, are herbivores. Examples in Canada are witches broom (*Arceuthobium*), Beech Drops (*Epiphagus*), and One-flowered Broom-rape (*Orobanche*). Likewise, fungi that are parasitic on plants are functional herbivores.

Herbivory is carried out by viruses, bacteria, protozoans and many filter feeders: rotifers, many molluscs, many crustaceans; non-filter feeders: nematodes, most insects, symphylids, springtails, waterbears, kinorhynchs, starfish, urchins, many fishes, amphibians (larval stage), some reptiles, many birds and mammals, and technically, by plant parasites on plants as noted above.

4.4 CARNIVORY

The killing and eating of animals by other animals for food is carnivory. This is nature's way of evolving far more biodiversity than would otherwise exist. In Canada, drastic impairment of the carnivory function has taken place with many large carnivores now in decline and under pressure for survival (Burnett *et al*. 1989; Hummel and Pettigrew 1991). Examples are the grizzly bear, wolverine, timber wolf, beluga, sea otter, bowhead whale, right whale, blue walleye, lobster, Atlantic cod, tuna and many others. Well-known Canadian carnivores are found among the larger mammals, as for example, seals, polar bears, members of the weasel family, canines like foxes, coyotes and wolves, cats like the mountain lion, bobcat and lynx, and some others. Many birds and countless invertebrates are carnivores. Fish such as tuna, halibut, and many others are carnivores.

In forested regions of Canada, the cutting of new forest access roads into formerly roadless areas is one important cause of some of these declines of large carnivores, since continuous habitat is fragmented (Harris 1984; Maser 1988) and the new networks of roads provide ready access for hunters, trappers, and poachers using mechanized vehicles and other high technology to locate these animals. The development and spreading use of all terrain vehicles is now posing an additional threat to Canada's largest terrestrial carnivores since even roadless areas are now frequently entered for purposes of hunting and poaching. Technically, some Canadian plants such as sundews (*Drosera*) and pitcher-plants (*Sarracenia*) are carnivores.

All animal and proctist parasites that live on animals are functional carnivores since they are totally dependent upon the host animals for food. The phenomenon of parasitism is widespread in marine, terrestrial, and freshwater organisms as indicated in Appendix 1. Some biologists refer to parasitism as obligate symbiosis (see section 4.10 below).

Herbivory and carnivory as functions evolved relatively early in the history of animal life on Earth, an evolution that has continued to the present. These functions originated within natural systems operating freely under the workings of natural laws.

The carnivory function is carried out by viruses, bacteria, protozoas and all filter feeders: sponges, hydroids, combjellies, various worm groups, molluscs, many crustaceans, all spiders, many insects, all centipedes, all lampreys, sharks, bony fishes, amphibians, most reptiles, and many birds and mammals.

4.5 POPULATION MODERATION

This ecological function of organisms is a specialized subset of herbivory and carnivory. The recognition of population moderation as an ecological function identifies not only the mere presence of herbivores and carnivores, but the special major effect that activities of selected herbivores and carnivores have upon relative abundance of species that they weaken, kill and/or eat. Herbivores and carnivores that can act to systematically or abruptly constrain the abundance of other species play critical roles in determining the dynamics of ecosystems. Such "controlling" organisms are widespread and include "diseases", "parasites", "insect pests", and "predators".

Many viruses, bacteria, infectious microfauna, parasites, and invertebrate and vertebrate carnivores are regarded by humans as undesirable. But the population moderation function of organisms is responsible for the evolution of a far greater amount of biodiversity than would otherwise be the case. By limiting the abundance of potentially dominant species, moderators foster the survival and diversification of secondary species. In balanced ecosystems where species live together in innumerable harmonious ways, the "outbreaks" or "blooms" of organisms that can swamp out other species do not often occur.

The particular role of certain species in moderating populations is graphically displayed by examining population explosions where exotic species have been introduced into the country without their natural moderating or controlling species. The spread of purple loosestrife, frog-bit (Catling *et al.* 1988), starlings, chestnut blight, carp, zebra mussels, and other alien species in Canada provide good examples of a lack of moderators, as described above. Table 5 lists exotic species that have seriously affected native ecosystems and species.

As noted in section 4.3 above, parasitism on plants is a special kind of herbivory. Many plant species are parasitized by smuts, rusts, and other fungal organisms such as Dutch Elm Disease or the Chestnut Blight (Table 5). The effects on the ecological structure of forest communities can be dramatic and change populations of dependent invertebrates and vertebrates. As a result of the parasitic "herbivory", plant populations can be changed with respect to both their genetic and their ecosystem structure, according to Burdon (1993), who points out that the number of species (and including viruses) attacking plants is enormous.

The population moderation function is carried out by viruses, bacteria, fungi, many invertebrates and vertebrates, including many herbivores and carnivores.

4.6 NUTRIENT TRANSPORT (BY INDIVIDUAL ORGANISMS)

Nutrient transport is a general function of all organisms. In the case of higher plants, nutrients absorbed from the soil accumulate in wood and leaves, and as these decay nutrients are deposited in different ways and places. Nurse logs in forests are well known. Leaves transported by wind or ending up as detritus in streams and lakeshores provide food and nutrients for soil and aquatic invertebrates. In the case of animals, all species are involved in such transport in the sense that during their lifetimes they urinate and defecate somewhere and when they die, their load of body nutrients ends up at a particular spot. These nutrients are then made available to primary producers by scavengers and decomposers. In the Arctic, it is common to see intense green vegetation around animal burrows and in the immediate vicinity of animal carcasses. Droppings of many animals provide needed food for insects, which in turn would not be present to serve as food for birds, etc. Most recently, there has been an enormous increase in our understanding of the role of fungi in transferring phosphorus, potassium, and possibly nitrogen through extensive networks of soil hyphae. The role of soil fungi in nutrient transport is now seen as critical to the production of tree biomass in temperate forests of the world (Hawksworth 1990; Hammond 1991; Kendrick 1992).

Taxonomic groups that carry out major nutrient transport functions are fungi, plants and mobile animals.

4.7 SEQUESTERING OF CARBON DIOXIDE

Many groups of micro-organisms, animals, and plants perform the function of removing large amounts of carbon dioxide from the air and waters. The carbon is said to be stored in living and dead organisms, fossil coal, and petroleum.

Forests, in particular old growth forests (together with their woody fragments and soil systems), as well as the enormous populations of marine plankton, both plant and animal, are major repositories for carbon. Additionally, bogs and fens are repositories for carbon because they store large deposits of peat. In the oceans, perhaps the largest amounts of carbon sequestered by living things is locked up in marine limestone deposited by species of foraminifera (protozoa) whose limestone shells constantly rain down upon shallow parts of ocean floors. Recent studies have shown that the ocean itself is a significant sink for anthropogenic carbon dioxide (Siegenthaler and Sarmiento 1993), taking up about one-third of emissions arising from fossil fuel use and tropical deforestation. The authors suggest that the "terrestrial biosphere" may be responsible for removal of a considerable percentage as well.

Global warming due to accumulation of greenhouse gases in the atmosphere has become a worldwide issue and recently led to an international convention on this emerging problem.

This ecological function is carried out by charophytes, chrysophytes (which make limestone plates and ooze), cyanobacteria, algal proctists, all living biomass in freshwaters, oceans, soils and on land (e.g. trees), protozoans in the form of deposits of marine chalk and limestone, hydroids in their creation of coral reefs, molluscs and lamp shells, and mosses and other plants that deposit peat in fens and bogs.

4.8 SEED AND SPORE DISPERSAL (PLANTS); MIGRATION (ANIMALS)

The dispersal and migration function of plants and animals has shaped the evolution of life profoundly on continents, islands, and oceans. Island biogeography is the study of the consequences of the differential capacity of biota to disperse or migrate onto distant islands surrounded by ocean and then evolve new forms or species as a result of isolation. As well, in areas of continuous land mass, the constant movement of spores, seeds, or individual organisms is a major factor in shaping the genetic variability, composition, and distribution of species and the local composition and evolution of ecosystems.

The function of dispersal of spores and seeds and of the migration of animals ensures that species live in as large a range as climate and habitat will allow, despite ongoing local extirpations caused by natural or human means. Dispersal and migration re-establish populations of species in areas where natural catastrophes may have eliminated local populations, and in areas such as abandoned farm land where human activities may have previously converted natural ecosystems to human uses. Birds, mammals, insects, and other groups play ongoing roles in the spread of seeds and spores as do wind and water.

A major cause of species loss today is the fragmentation of previously continuous habitat over large regions. Many species simply cannot breed successfully in fragmented ecosystems for a variety of reasons (predation, inbreeding, interference with daily/seasonal movements, lack of pollinators, etc.). Recolonization of fragments of suitable habitat from other areas or regions is a constant necessity. For example, woodland birds (warblers, vireos, flycatchers, etc.) attempting to nest in fragments of forest across southern Ontario are subject to significant parasitism by the brown-headed cowbird. Scott and Ankney (1980) report that an average female lays up to 40 eggs per season. As well, we see predation by grackles, crows, blue jays, and raccoons at a scale that can reduce reproduction to zero or near zero in such habitats. Fragmented landscapes can be true sinks for many breeding birds since even replacement of adults is not possible. Only influx from nearby non-fragmented regions makes it possible for these birds to be present in such places.

This function is carried out at varied levels of efficiency by all organisms, either by their own activities or with the assistance of their abiotic environment.

4.9 CONTROL OF SOIL EROSION

The structural function of vegetation and its root systems in preventing soil erosion and allowing for the gradual development of deep productive soils is well known. Accumulations of leaves, branchlets and stems also break the force of raindrops and running water thus assisting with soil retention and its development (Section 4.11). Burrowing organisms that perforate the soil divert flow of precipitation into the soil and reduce surface runoff and erosion (McAllister 1993g).

This function is carried out by mosses, ferns, horsetails, lycopods, conifers, and flowering plants. In marine regions, protection for sediment is provided by eel grasses, sponges, corals (by forming local barriers against oceanic waves), and mangroves.

4.10 SYMBIOSIS

Symbiosis is the mutually beneficial intimate association of species with unrelated species of fungi, animals or plants. In this report only mutually beneficial, intimate co-evolved associations are considered to be symbiotic. These are called "mutualisms" by some ecologists (Begon *et al.* 1990, 434). There are numerous examples in nature where a larger organism (called the host) provides a body, nest, shelter, etc., on which a smaller organism lives with no benefit to the host; these are not symbiotic associations as defined here.

Symbiosis is an extremely common phenomenon in virtually all phyla of living things (Parker 1982; Margulis and Schwartz 1988; Brusca and Brusca 1990; Begon *et al.* 1990). It is a controlling factor in maintaining ecosystem productivity and richness and in generating new kinds of biodiversity. Some major kinds of symbiotic associations are: nitrogen fixation; mycorrhizal associations between fungi and plant roots where fungi make possible the more efficient mineral absorption by herbs and trees (Tacon *et al.* 1987; Cherfas 1991; Hawksworth 1991a, 1992); lichen partnerships involving algae or cyanobacteria with fungi where nutrients are provided to the host while living space is provided for the algae or cyanobacteria; algae living in cells of coelenterates; partnerships between bacteria and echinoderms (Bosch 1992); partnerships where bacteria, protozoans or fungi live right in the gut of their host animals; mutually beneficial relationships between ants and aphids, ants and fungi, associations between legume roots and nitrogen-fixing bacteria, among others.

Nitrogen Fixation. The ability to capture atmospheric nitrogen and make this available in a form that can be used by plants is not a widespread function among organisms. However, where it does occur, the results are important since they can determine ecosystem characteristics. Nitrogen fixation occurs among some flowering plants such as legumes, alders (*Alnus*), and wax-myrtles (*Myrica*). The fixation is made possible through a symbiotic presence of nitrogen-fixing bacteria in certain cells of the host plant. When such plants die, the fixed nitrogen becomes available to other plants in the immediate vicinity. As noted above, nitrogen fixation also occurs widely in lichens which themselves may be extremely abundant in large parts of northern Canada. However, there is no evidence that mycorrhizal fungi, or any fungi for that matter, can fix atmospheric nitrogen, so that in most mycorrhizal plants, when increased concentrations of nitrogen have been recorded, they must result from increased uptake from the soil (Harley and Smith 1983). However, nitrogen fixing bacteria sometimes also live within the hyphae of mycorrhizal fungi, thus steadily producing tiny amounts of nitrogen, which can then be transferred to tree roots through the fungal-root connections (Maser 1987 in Hammond 1991). Plants having the ability to form symbiotic relationships with bacteria that fix nitrogen are widely used in increasing agricultural production. Apparently all legumes used in Canadian agriculture have this capacity, including clovers, vetches, birdsfoot trefoil, soybeans, alfalfa, sweet clover, and possibly others, some of which have mycorrhizal associations as well.

Mycorrhizal Associations. An estimated 80 to 90% of higher plants belong to families that have root connections with associated fungi (Trappe 1987; Hawksworth 1992). These linkages, called mycorrhizae, provide for an exchange of nutrients and food between the fungi in the soil and the root hairs of the plants. Such mutually beneficial relationships are widespread in temperate forests and are considered to have a major importance to primary productivity of forest trees (Hawksworth 1992; McAllister 1993b).

Pollination. Animal mediated cross-pollination of flowers represents a dramatic co-evolution of symbiosis between flowers on the one hand, and insects, birds, and even bats on the other. In pollination, a third party (insect, bird, wind) is involved in transporting genetic material between individuals. This "mediating" function recognizes the co-evolutionary origins of morphological and chemical properties of flowers and the behavioral and sensory features of their visitors within the context of the ecological setting in which interactions take place (Real 1983). Co-evolved pollination systems are uniquely specialized forms of mutual symbiosis. They are extremely abundant throughout the higher plants, and it is highly unlikely that flowers in all their intricate specializations, great beauty, and varied scents would ever have arisen without the benefits derived from animals visiting flowers to obtain nectar and pollen. Some of the more outstanding specialized systems have been described generally by Meeuse (1961), and for Ontario wildflowers and orchids in particular by Mosquin (1989a, 1989b). It should be noted as well that the so-called abiotic components of biodiversity (see Chapter 2), namely wind and water, have also been instrumental in transporting pollen between many trees, shrubs and herbs. In Canada, most trees, many shrubs, grasses, sedges, cattails, and many forbs are wind-pollinated. As well, pollen is carried by water in marsh plants such as the water shield, *Brassenia schreberi*, American eel grass, *Vallisneria americana*, the many species of *Potamogeton*, and possibly others.

Bioluminescence. Another unique kind of symbiosis is bioluminescence. This is the cool light emitted by certain marine and terrestrial organisms. While in some cases such chemical light is produced by the organism itself, in many cases it is made possible by the presence of symbiotic bacteria (which emit light) that the host shelters and nourishes. Plankton, many mid-water ocean fishes, some shallow water fishes, squids, and other marine organisms exhibit the phenomenon of bioluminescence. In oceanic waters bioluminescence occurs in fish species that live in the darkness up to 1,000 metres deep. The living light may be a significant source of illumination. For individual fish species, the light organs serve for species and mate recognition (a form of communication), lures to attract prey, as "countershading" to camouflage silhouettes of prey species, and as startle devices to distract predators. For non-target individuals, the bioluminescence provides background illumination for vision. In other species, the function of bioluminescence is unknown (McAllister 1967; Johnson and Haneda 1966).

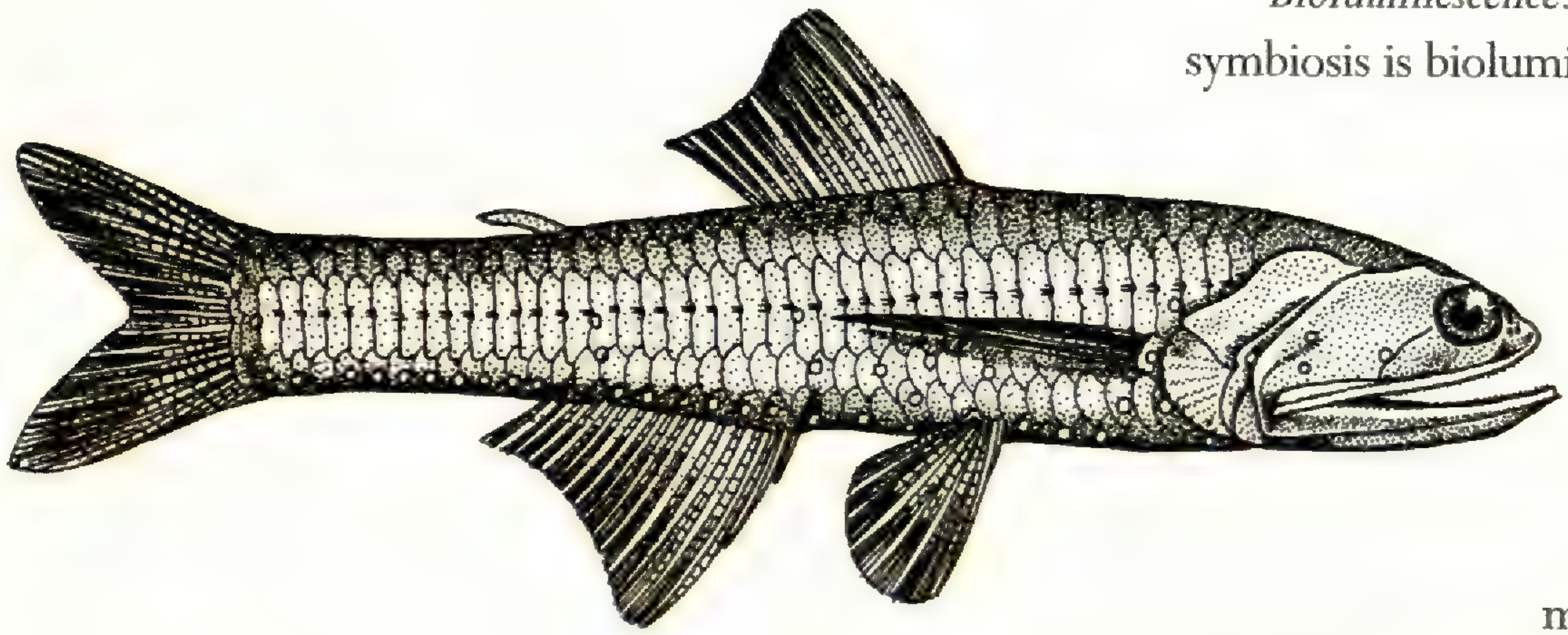


FIGURE 4

Jewel lantern fish, *Lampanyctus crocodilus.* The lantern fishes inhabit middle depths of the ocean during the day and migrate up towards the surface at night. The black circles on their sides are photophores, light organs which glow to help conceal the fishes shadow from predators below and serve as communication devices with its own species *(drawing from Jordan & Evermann, 1896,* Fishes of North and Middle America*).*

Most taxonomic groups listed in Appendix 1 participate in symbiotic associations in one way or another.

4.11 SOIL CREATION AND SEDIMENT BIOTURBATION

Soils are unique living ecosystems that are created by living organisms, present by the tens of thousands in a single cubic centimetre. Soils are very different from regolith (the "soil" of the moon or Mars). An enormous number of biochemical processes take place in soils, including decomposition recycling of carbon and nutrient transport. The growth of roots, fungal hyphae and the tunnelling by worms and other soil invertebrates helps to build, aerate, and maintain soils (Brady 1984). In marine regions, many species live in the sediment, and are constantly recycling or mixing sediment from deeper layers.

Taxonomic groups that have major roles in carrying out this function include bacteria, cyanobacteria, algae, fungi, numerous invertebrates, and plants (roots, leaves, dead trunks). In oceans, all bottom dwelling groups that burrow in sediment or bore holes in rocks or chew up coral to make sand also perform this function.

4.12 MODERATION OF MACRO- AND MICROCLIMATE

Climate has a major determining affect on vegetation. Macroclimate is the prevailing or average weather conditions of an area or region as determined by the temperature and meteorological condition over a period of years. Macroclimate is the single most dominating influence upon the kinds of plants and animals that can develop and live in any region and the kind of ecosystems that develop. Whether one finds tundra, boreal forest, prairie, or west coast rain forest is a function of macroclimate. However, once firmly established, vegetation may significantly affect local and nearby ecosystems through its influence on albedo (the percentage of sunlight reflected from an area) and through the effect of transpiration on relative humidity, fog, and rainfall.

In terrestrial ecosystems, the effect of plants upon the "climate near the ground" is profound. Standing forest trees, shrubs, forbs, grasses, and mosses have major moderating influences upon the microflora and fauna of an area due to effects of shading and humidity. In areas devoid of plant cover (such as deserts or cultivated fields), extremes of light intensity, humidity and temperature, as well as wind, can be great, affecting the evolution of biota in profound ways. Fungi, roots, worms, and other soil invertebrates perforate the soil, increasing water penetration and retention, and reducing surface runoff. Water-absorbing humus builds up in grasslands, forests, and other natural systems. Moisture is retained following heavy precipitation or during runoff, thus adding stability to the moisture and drought peaks of the atmosphere and stabilizing the run-off into streams (McAllister 1993g). Water cycles are affected by urbanization and clearing of land for agriculture in the sense that such disturbed areas have more surface runoff than that which occurs in natural systems. In such places, flooding may be intense, and animal species may be absent, seek shelter underground, or move to more hospitable areas.

4.13 DECOMPOSITION (PRIMARY & SECONDARY DETRITIVORY)

Decomposition is the natural recycling of dead or waste matter (residues of life) by many species. Next to primary production, decomposition is the most important of ecological functions of organisms. Many phyla of organisms participate in this essential function (Appendix 1), which takes place universally in soils, and in fresh and marine waters. Life on Earth would not be able to survive without the ecological functions and services of primary and secondary detritivores because there would be no way of cleansing the ecosphere of the "products" of life. Indeed, the great oil deposits of the world may owe their existence to the lack of the full development of this function in earlier times.

Primary detritivory is the absorption (through the exterior coat or skin) of free organic molecules as food for growth and development. Bacteria obtain all their food in this way, as do fungi and two phyla of animals—the marine worms—pogonophorans and vestimentiferans (Appendix 1). Bacteria metabolize these "organic soups of life" to create nutritive blocks (called plaques) that are eaten by multitudes of protozoa and other plankton, which (together with photosynthesizing algae and cyanobacteria) are the primary "pastures" for all protozoans and ultimately of animals in freshwater and marine food chains.

Secondary detritivory is the direct ingesting of animal and plant tissue as food and its conversion into living animal biomass. (Part of secondary detritivory is in fact herbivory and carnivory since living organisms are often included among the detritus and being eaten—attesting to the linkages between functions). A wide range of animals from bacteria, to bottom feeding fishes and vultures are classed as detritivores. As well, any and all "filter feeders" in freshwater and marine ecosystems are also secondary detritivores because they cannot discriminate between living planktonic organisms and floating dead tissue biomass.

Many phyla of bacteria (Margulis and Schwartz 1988) have developed what is clearly the important ecological function of ingesting toxic organic molecules and reducing a portion of them to less harmful substances and minerals. Mineralizing bacteria can be amazingly abundant in many ecosystems and thus play unique functions in maintaining the health of associated organisms, local and regional ecosystems, and the planetary ecosphere as a whole.

Fermentation is a specialized kind of decomposition. It is the enzymatic transformation of organic substances, especially carbohydrates, and is generally accompanied by the evolution of a gas. Fermentation is a physiological counterpart of oxidation and permits certain organisms to live and thrive in the absence of oxygen. Indeed, oxygen is toxic to most anaerobic organisms. Only some fungi and some anaerobic bacteria can perform the function of fermentation, particularly important to humans for processes such as the making of cheeses, breads and alcoholic beverages. In natural ecosystems, fermentation is widespread in soils where organic substrates abound. It is particularly effective in sewage ponds, anaerobic sediments, and in waters where available oxygen has been consumed by input of municipal sewage or decaying aquatic "weeds" and where oxygen supply is too low for the support of the usual aerobic organisms of the aquatic ecosystem.

4.14 MAINTENANCE OF 3-D STRUCTURES

The capability of many different phyla to evolve multicellular forms is the basis for this function. One can only imagine how impoverished the Earth's ecosystems would be if the planet's early life forms had not been able to evolve into complex multicellular structures. Today, two of the five kingdoms (plants and animals) are exclusively multicellular, while two others (proctists and fungi) have both unicellular and multicellular species. A few bacteria are multicellular.

The consequence over time has been the emergence of forests, tundra, prairie, kelp beds, submergent freshwater plants, coral reefs, and other very complicated and beautiful ecosystems. As a consequence of multicellularity, entire assemblages of new life forms have been able to evolve, both within and among the multicellular organisms, in seemingly improbable complex ecosystems that take on new functions of their own. Of course, some ecosystems do not occupy as large a volume of space as others, as for example, grassland or tundra or exposed bare rock surfaces covered with lichens, but they are nevertheless three-dimensional and provide habitats for many smaller species. Larger animals and plants themselves provide habitat on and within their bodies for a great variety of other species.

Multicellular organisms as such, however organized, are only one aspect of the evolution and functioning of biodiversity. As noted earlier (Table 3), there is the matrix in which biodiversity dwells and from which it is inseparable and at unity. Thus, these ecosystems would not be possible without the enabling media of volumes of water, rock, soil, and air. Soils, for example, contain spaces where we have seen the emergence of a rich three-dimensional medium in which roots of plants, fungal hyphae and the burrowing of mammals, nemotodes and insects all take place, and where an incredibly diverse assemblage of micro-invertebrates live. One has to ponder this encompassing dynamic when walking through a forest or diving among corals or kelp beds. All-of-us-together are encased absolutely in the planet's ecospheric medium. It is with this awareness of our place in the collective whole that we need to consider the highest and most complex levels of the functions of biodiversity—those at the level of the ecosystem.

Major taxonomic groups that carry out this structural function in marine areas include tall sponges, corals, macro-algae (green, red and brown), animals (especially the large ones); in terrestrial areas they include herbs, shrubs, trees, entire forests, the larger fungi and animals; in freshwater areas they include all submergent vegetation and animals.

4.15 COMMUNICATION

Communication is an ecological function because it has profound effects upon the substance, nature, and quality of species and ecosystems. It is a major, widespread, and essential function of all complex life forms. A diverse array of methods and variations of contact between individuals of the same species and between different species have evolved and co-evolved and are now part of the natural taken-for-granted processes in ecosystems.

In more primitive organisms, simple chemical sensory abilities are widespread, enabling them to communicate for purposes of reproduction, the finding of food and so on. Among higher forms of life, communication includes the use of taste, sight, touch, sound, radar, sonar, the sending and detection of electric currents and other specialized methods. Sight (between organisms and between organisms and their surrounds) influences all manner of activity—courtship, parenting, food gathering, migration, herding, flocking, escape from carnivores. The capacity of some invertebrates and vertebrates to perceive colour has had a stupendous impact upon the evolution and origination of colour in birds, fish, mammals, and colour-perceiving insects like pollinating bees. Flower colours have evolved in response to the capacity of the higher pollinating insects to see colour. The great intricacies of mimicry, so widespread among insects, is the direct result of the ability of insect eating birds to perceive differences not only in the shape of their insect food but in its colour, taste and insect behaviour. Pheromones released by female insects ready to mate attract males from distances in excess of a kilometre. Substances released from injured skins of minnows (cyprinidae) alert several species of minnows to the possible presence of a predator. The warning calls of birds are commonly understood by several species.

Likewise, the evolution of the ability to use sound in communication has produced what can only be described as a truly wondrous diversity of bird, animal and insect sound and song, enriching the beauty of natural ecosystems beyond the bounds of imagination. As well, it is of interest to note that much of the communication taking place in natural ecosystems cannot be sensed by humans, except through the use of scientific instruments. In the sense that communication is the very product of the evolution of biodiversity, there can be little doubt that much that is beautiful and meaningful in this world is vanishing permanently as biodiversity is reduced. Many symbiotic functions require a number of communication functions to operate.

This powerful function has evolved in myriads of different ways. Each taxonomic group has its particular kind or kinds of communication in different parts of its life cycle.

4.16 FOOD WEBS (TROPHIC STRUCTURE)

The pattern of movement of energy through organisms in communities defines "trophic structure". The conservation literature refers to this pervasive function of ecosystems as food webs. All food webs begin with the biomass produced by a variety of primary producers (Table 2; Appendix 1). The particular taxonomic groups include two phyla of bacteria, algae, lichens, and plants—all of which uniquely occupy the first or lowest trophic level in any ecosystem in which they occur. Most bacteria and all fungi, protozoans and animals cannot manufacture their own food and are hence always at higher (dependent) trophic levels. A detailed discussion of trophic structures is presented in Begon *et al.* (1990, 798-815).

Trophic levels may or may not be discrete. Among plants and mammalian vertebrates, for example, primary producers are eaten by herbivores, which are then eaten by other vertebrate carnivores. Among them, the evidence of discrete levels is obvious. However, the trophic structure among micro-organisms and invertebrates can be more complex because many invertebrates are filter feeders and most zooplankton will ingest any bit of organic material, whether it be phytoplankton, bacteria, other zooplankton, or detritus from the decomposition of plants or animals. Size of the organism or particle is one determining factor affecting trophic pathways and levels among the varied food chains of these biota. Likewise, the trophic levels and relationships among soil biota and sediments are poorly understood because most of their species have not even been described by science (column 4 of Appendix 1). Obviously, in these circumstances there are many interlocking levels and "feedback" chains in the sense that consumers are neither 100% herbivorous grazers, nor 100% carnivorous predators at a single or different life history stage, and that energy can move through the system through different kinds of cycles or through cycles within cycles. In other words, the trophic structures of micro-organisms, most soil biota, and filter feeding invertebrates can be taxonomically diverse.

While knowledge of trophic structures among terrestrial vertebrate and plant resource species tends to be adequate for making management decisions, this is not the case with freshwater and marine systems. In the latter, intense overexploitation of species at higher levels in the food web has taken place in circumstances of near total ignorance of the underlying trophic support systems upon which the production of these biological resources is founded—the Atlantic fishery collapse is one example.

4.17 BIOGEOCHEMICAL NUTRIENT CYCLING (ECOSYSTEM AND ECOSPHERIC SCALE)

Nutrients can be recycled and reused repeatedly within ecosystems and the ecosphere. Brief overviews exist in ecology textbooks (e.g. Begon *et al.* 1990, 681-710). All major elements required by plants and animals move in cycles within the organic part of communities (the biosphere) and in other cycles from the biosphere to the atmosphere, hydrosphere, and lithosphere and back to the biota again. All essential nutrients, including trace elements, are involved in these cycles. Nutrient cycling is an ecosystem level function because nutrients are essential to organisms and because of the pervasive and complex pathways and geochemical processes involved. The term "biogeochemical" cycles has been coined to describe the nature of this phenomenon. Its pervasive and essential presence is an explicit example of the fifth inseparable dimension of biodiversity, namely the abiotic biodiversity matrix as described in Chapter 2 and Table 3. To appreciate the scale and the implications of the movement of nutrients from the hydrosphere and lithosphere into living organisms and back again, consider the example of calcium: all calcium carbonate of the great limestone deposits of the Earth was precipitated from dissolved carbon dioxide by living organisms in marine systems (*Globigerina*, molluscs, corals, etc. See function 4.7 above). Hence, the bones of vertebrates and calcarious shells of the animal kingdom have been made possible by the abundance of "bio" calcium carbonate. To glimpse the nature and extent of ecospheric nutrient cycles, the reader is referred to standard ecology textbooks such as the one cited above.

Human activities (through agriculture, industry, municipalities) are adding abnormal amounts of nutrients into waters, soils, and the atmosphere. The consequence is overfertilized lands, and eutrophic fresh and marine waters to the extent that the functioning and kinds of natural ecosystems in lakes, forests, or marine shorelines are drastically affected. Such eutrophication results in major substitutions of species present and therefore in the functions of species and ecosystems of affected areas. Many streams, rivers, and lakes in Canada are highly eutrophic, their waters turbid with micro-organisms, and their productivity and biological resources drastically altered from the norm. Eutrophication has been reduced in some waters through the introduction of low-phosphate detergents.

4.18 MAINTENANCE OF GENETIC DIVERSITY

The exchange of genetic material between individuals within and sometimes between species is an ecosystem function in the sense that an enormous panoply of mediating agents, both biotic and "abiotic" are involved in transferring genetic material during reproduction. While mechanisms of reproduction may be internal or co-evolved, they range from ones that clearly maintain or promote genetic variability to ones that appear to be aimed at limiting genetic diversity in a species through vegetative, sporulating or similar types of reproduction.

The specific mechanism that maintains genetic variability among animals is bisexuality, meaning that a near universal genetic system of two sexes is present in each species, but with "asexual" reproduction or hermaphroditism playing a role in some species. In contrast, in plants, mechanisms maintaining genetic diversity are: dioecy (two sexes), monoecy (separate male and female flowers on the same plant), heterostyly (genetically different individuals in the same species with different style and stamen lengths that enable or require cross-pollination), gynodioecy (some plants only female, others with male and female flowers), dichogamy (different timing of maturation of anthers and stigmas of the same flower), and various incompatibility systems. Those restricting genetic diversity include inbreeding, buffering by polyploidy, apomixis, among some others (Mosquin 1966). All these forms of reproduction (except strict self-pollination) are "mediated" by the matrix (climate, specialized habitat, edaphic conditions, etc.) in which individuals of a species can combine genetic material to create the next generation.

On a year-to-year basis weather plays a major role in the success or failure of reproduction in many groups. For example, the impact of cool, rainy weather on butterfly reproduction during the mating and egg laying season is dramatic. Pollination in outcrossing plant species may be severely inhibited when needed pollinators are absent or rare. Thus, genetic variability is controlled or promoted within the sum total of attributes of the ecosystem, while the health and viability of progeny in any population are dependent upon both the genetic system of the species, the effective size of the population, and the suitability of its immediate habitat.

Aside from ecosystem characteristics having a dominant role in success or failure of reproduction, the function of dispersal or migration (section 4.8 above) plays a key part in the ability of a species to control its genetic diversity. Among animal populations, critical size of an effectively breeding remnant population is frequently a function of some factor in the ecosystem, for example, natural loss of habitat, intensity of overexploitation, fragmentation, and others. Many cases are known worldwide where animal populations have been reduced to such low levels that reproduction success among the surviving individuals is very low, with the possibility of extinction due to inbreeding depression. In the wild, some factor operating in the ecosystem (usually humans in today's world, or a successful exotic introduced by humans) is the prime cause of such reductions in genetic variability.

4.19 STABILITY

The geological and historical basis for recognizing stability as an ecosystem function stems from practical observations and scientific knowledge that natural ecosystems (and all or most of their component species) have remarkable staying power when left more or less to their own devices. This persistence and perseverance is not measured only in terms of centuries. Rather, over hundreds of millions of years, a stupendous variety of continuing ecosystems has developed in terrestrial, freshwater, and marine regions. They persisted, diversified in species, acquired new ecological functions, and extended themselves into all habitable parts of the Earth. The slow origination of these complex systems occurred despite (possibly helped along by) major physical changes in the Earth's climate and indeed it was life itself that once created and today maintains the very basis for continuing evolution and survival.

The notion that even today's natural systems are stable (when major human impact is prevented) is encapsulated by the phrase "balance of nature", which is widely held to be self-evident, based on lifelong experiences and observations of people living in the countryside or relatively close to nature. To analyze and describe the elements of this stability or balance is a formidable task, but some ecologically minded scientists are attempting to do so (Schneider and Boston 1991). However, it is not the place of this report to review the different theories attempting to account for the persistence of natural systems, their resilience, and their resistance to change over long spans of time. A few examples of the basic elements contributing to stability will suffice here. Of course, we are referring here to relatively natural systems, not ones that are being transformed or eliminated by human activities and associated introductions of exotic species.

Connectedness: The observation that *"everything is connected to everything else"* is an essential element of stability, since species need to meet their requirements in consort with hosts of others and through cycles, trophic levels, dispersal, and other functions that involve most or all of them either permanently or from time to time.

Redundancy: The controversial notion that many species in an ecosystem may be surplus to the requirements of the system is reviewed by Lawson and Brown (1993). The theory is based on modelling experiments and not on direct evidence. A redundant species would be one that had essentially identical functions in ecosystems as several companion species, and where it is theorized a loss of one or two of them would not change the characteristics of the ecosystem. Examples would be 20 species of single-celled green algae in a pond (all free-floating), 5 species of bumblebees in a meadow (all opportunistic pollinators), or 10 species of deciduous trees in a forest (all of which provide the principal canopy), etc. However, whether such purportedly redundant species are really surplus to the ecosystem (in terms of functions performed) is difficult to prove. Genetic and chemical differences may well mean that opportunities exist to interact uniquely with other species or that so-called redundancy is really a major positive mechanism for buffering ecosystems against abrupt change, which would enhance both short- and long-term stability. For example, a seemingly redundant species may play a more important role in exceptionally wet, warm, or cold years. As well, a species that appears redundant today within the ecosystem in which it occurs may be the sole foundation through which a wholly new ecological function originates at some point in the future.

Generalist Behaviour: Stability in ecosystems would be enhanced in cases where an important species, such as a pollinating bee, would care little as to which flowers were available for nectar and pollen and as a result of its activities, numerous outcrossing plants would be pollinated. Or, when a particular carnivore could exploit many different kinds of prey, its continuing presence in the ecosystem would not be jeopardized by the extirpation of one of its food species. These are examples of where fluctuations in species numbers are dampened by spreading risk (Lawson and Brown 1993).

Keystone Species: A keystone species is one that has a disproportionate effect upon the persistence of all other species (Bond 1993). Keystone species are of different types: carnivores (mountain lions, killer whales, sea otters), herbivores (snowshoe hares, caribou), competitors (aggressive exotics, dominant forest trees), symbionts (major pollinators, mycorrhizal fungi of dominant trees), earth-movers (earthworms, pocket gophers); plants that alter the fire regime (producing major fire loads), and system processors (nitrogen fixers like lichens and *Alnus*). The presence or absence of these kinds of keystone species will have a significant effect upon affected species and hence help determine the stability of different parts of the ecosystem.

Trophic Complexity: The length of food webs in a community (number of levels) may also have a bearing on stability in a community—communities with fewer and less complex food webs being the more stable. According to some models (Lawton and Pimm 1980 in Begon *et al.* 1990), webs with more trophic levels underwent such severe fluctuations as to lead to the extirpation of top carnivores. However, the extent to which such effects of food chain disruptions would affect species richness over large landscape regions is largely speculative.

Complexity of Communities: Modelling exercises predict that communities rich in species are less stable than ones with few species, although the relationship is not clearcut. There appears to be strong agreement among ecologists that it would be far more difficult to restore a species rich community (following major elimination of species) than a species poor one (Begon *et al.* 1990, 801). Schultze and Mooney (1993, 507) note that "stability may decrease or increase with reductions in species number in a given system, and the effect may be different in temperate, tropical, and arctic habitats".

Fire: The effect of fire upon ecosystem stability is evident when very large landscape regions are considered. Repeated local fires in ecosystems prone to fire (boreal forest, lodgepole pine forest, prairie) greatly increase the overall complexity of communities and create numerous successional stages that can support a far wider variety of biota than if fire were absent from these regions. Such stability of ecosystems has been described for Banff National Park (White and Pengally 1992), where Parks Canada has instituted a fire-management policy to encourage biodiversity and maintain a permanent patchy disturbance (i.e. stable) regime. Storms, droughts, high and low snowfalls, ice storms, and other climatic events also influence patchiness.

Finally, as noted earlier, the "Gaia" hypothesis postulates that the ecosphere is stable because its ecosystems (through the functions of their species) have worked to create a self-regulating system. That stability, however, does not mean that the ecosphere is invulnerable to major perturbations, by humans, volcanic activity, or the impact of large meteorites.

4.20 COMMUNITY SUCCESSION

Community succession is a function of ecosystems because of the large numbers of species involved and its links to disturbance regimes, geography, and shifting climate. In a limited sense, succession is a subset of stability. Succession is defined as a continuous directional change in an ecosystem at a particular site lasting dozens or hundreds of years and involving both colonization and extirpation of species in all parts of the ecosystem. The unique genetic characteristics of individuals in each species ultimately determine whether or not any species can invade and be present in a particular community. Genetic traits also determine the species' abundance and the rate and timing of its return to and disappearance from communities disturbed by fire, storms, insect herbivory, and other sudden impacts.

Many of the above described functions play critical roles in community succession and therefore in the occurance of species in an ecosystem one observes at a particular place. For example, one such function is mutualistic symbiosis between plants and various microbes or insects (Real 1983; Hawksworth 1992; Read *et al*. 1993) in different kinds of terrestrial communities. The presence or absence of various mycorrhizal fungi can be strong determining factors in the kind of succession that is possible following major alterations to the soils, for example, at a site following clearcutting and deep soil fire (where the fungal mat has been burned off), or a prairie site that has been plowed down, etc. Plant species that do not require mycorrhizal fungi are less constrained successionally since they do not need a soil containing mycorrhizal fungi. Another example of how functions can determine the sequence of species succession would be the invasion of light tolerant or shade requiring plant species into a community where dispersal by a variety of means is taking place. Following disturbance, when the community at a site is considered to have reached a "steady state" (i.e. no net gain or loss of species over a period of time), succession would no longer be taking place.

Should major global warming become a reality, the genetic properties of individual species and their dispersal capabilities will determine their success in spreading to new regions and altering the ecosystems present there as a result of earlier succession.

4.21 HARMONY

Harmony is identified as the ultimate consequence of the workings of the 20 functions noted above. Diverse, pervasive, and persistent, harmonies in nature exist at all levels, which contribute to maintaining the whole. Some unique aspects or elements of the harmony function are: animal and plant form; the obvious grace of animal movement (swimming, flight, running); colours of birds, fish, butterflies, flowers, and the appearance of a unicellular algae under a microscope (Augros and Stancieu 1988, 130-155). These phenomena have come into being without humans exercising their judgements or powers.

At a higher, integrative level, the function of harmony includes the workings and appearance of entire ecosystems and must encompass the matrix of the flowing waters of rivers and streams, waterfalls, the pounding of oceanic surf, gentle and rugged landscapes, cloud formations, winds and weather (to which organisms and ecosystems are harmoniously adapted). Ultimately, harmony is bound up with wholeness, connectedness, health, and integrity. By recognizing harmony as a function of biodiversity, we are able to sense that when contemplating biodiversity, infinitely more is at hand than the mere production of biomass or the struggle for survival of individuals. To humans, the notion of natural beauty is encompassed by harmony. The philosophical and ethical dimension of the idea of beauty is a subject of discussion among philosophers and some scientists (Hanson 1986; Rowe 1986; Rowe 1990, 87-96).

The notion or observation that harmony has an obverse side helps to visualize it as one of the more encompassing integrating functions of biodiversity and of the planetary ecosphere as a whole. Thus, discord or ugliness results when organisms or ecosystems are reduced to fragments or parts. For example, a severed hand is an ugly thing, as is a cut off tree or head. At the level of ecosystems, the full expression of harmony is reduced when a road is cut through a previously natural forest, when a fully developed old forest is clearcut, when a river is severely polluted by a city, a chemical plant or pulp mill, when a lake is sterilized by acid rain, or when a coral reef disintegrates due to erosion-caused sedimentation and/or the presence of industrial and agricultural toxic chemicals. These are examples of processes that comprise the obverse, discordant, and destructive forces that reduce or destroy the long-evolved harmony of the ecosphere.

As outlined and discussed earlier (Chapter 3), recognizing and accepting norms for biodiversity is an essential starting point for assessing deviations. The same seems true of harmony. The obverse sides of harmony can provide another perspective on the merits of avoiding the destruction of nature's ancient norms as described in Chapter 3. The notion that humanity should organize its affairs in order to live off the interest rather than the capital of biodiversity (and hence retain optimum beauty, harmony, health, integrity, etc.) merits further exploration along the lines proposed in the book *Small is Beautiful: Economics as if People Mattered*, by Schumacher (1973). Major reductions in the demand for biological resources would be necessary to achieve such a goal, an issue considered in Chapter 7.

4.22 CONCLUDING COMMENTS

The variety of functions discussed above are certainly vanishing, and in many cases cannot be restored, a trend that is continuing and even accelerating as human populations increase exponentially. Since many dozens of unique ecosystems and their species are being eliminated and drastically modified in all settled regions of Canada and the world, we need to ask how these changes will affect biological resources and the quality of our lives in the future. One question is: how much biodiversity is needed in a country or the planet as a whole to keep the ecological services operating at approximately natural (i.e. time tested) levels? Few people are asking this question, which seems to be critical to humanity's future options, security, and life quality. According to Solbrig (1993, 111), "much more research is needed to determine precisely and rigorously the role of biodiversity in ecosystem function." However, the bottom line is this: we already know enough to be able to say that the question of the accelerating loss of biodiversity in all its aspects needs to be addressed at the political level, and indeed that is the intent of the Convention on Biological Diversity. Yet, despite the Convention and the beginning efforts of many countries to develop strategies to implement it, there is no evidence that negative trends can or will be reversed.

CHAPTER 5

TAXONOMIC AND ECOLOGICAL STATUS OF CANADA'S BIODIVERSITY

This chapter on the taxonomic and ecological state of Canadian biodiversity attempts to follow the guidelines set out by the United Nations Environment Programme (UNEP) (1991) to the extent practicable and assuming that information and knowledge were available. The UNEP guidelines provided the specific categories under which a country should collect, organize, and present information on the status of its biodiversity. However, in many areas where useful information on Canada's biodiversity was available, we have gone beyond requirements of the 1991 guidelines. UNEP has updated the draft version of the guidelines (UNEP 1993), but these have not been followed here.

5.1 TAXONOMIC CENSUS

Appendix 1 provides a comprehensive census of living organisms in Canada. Its purpose is fourfold: first, to report the total numbers of species described in all major taxonomic groups in the country; second, to estimate gaps in our knowledge from the numbers of undescribed or as yet unrecorded species in each of the groups; third, to record the principal environment(s) in which each group is found; and fourth, to briefly indicate the principal ecological functions performed by these groups. For most groups, the functions column is by no means complete, since taxonomic groups (particularly the larger invertebrate groups) contain diverse assemblages of species with widely varied life cycles, positions in food chains, habitats occupied and other "life style" variables. Only the most prominent or frequent functions for the group are recorded.

Appendix 1 is the first attempt to provide a complete taxonomic census of Canada's species biodiversity. The census includes terrestrial, freshwater, as well as marine species within Canada's 200 nautical mile oceanic limits on the Pacific and Atlantic coasts and within Canada's Arctic sector north to the north pole and down to the sea floor and including the organisms in marine sediments. The numerical information contained in the appendix has been slightly revised from that previously reported by Mosquin and Whiting (1992, Annex 1A).

The approach used in preparing Appendix 1 included literature searches, library work, telephone interviews, and visits with scientists familiar with or actively working on the Canadian flora and fauna, including micro-organisms. The information was assembled following what seemed to be a practicable classification at the level of Phylum, but occasionally we used Class and (in the case of insects) Order because insects are so diverse. The classification (but not the statistics on numbers of species) in Appendix 1 draws on a few principal sources, namely those of Parker (1982), Margulis and Schwartz (1988), Brusca and Brusca (1990), Kendrick (1992) and, in the case of the Orders of insects, Danks (1979, 1988), although none of these is followed exclusively.

While Appendix 1 is unique in its summary of taxonomic data and the ecological function characteristics of Canadian species, additional consultations with other research scientists, some ongoing research and further reviews of literature will inevitably result in major changes to the data for all the lesser known groups. The Appendix is a working "state of knowledge" report. Furthermore, not all functions have been listed for many of the taxonomic groups—especially for groups in the animal kingdom, since very often an obscure specialized species or genus has a very different functional role in its ecosystem than that of the bulk of the group.

The classification for the major groups as suggested in the UNEP Guidelines (1991) was found to be impractical for several reasons. The guidelines group a great number of important taxonomic groups. For example, the Algae (with 6 phyla rather than 10 as used here); the Arthropods with an "others" category, and some 25 "minor invertebrate phyla" are combined by UNEP into only one taxonomic group. In any analysis of species or functions, the combining of different phyla or classes obscures specific information on taxonomy, ecology, and ecological function. Taxonomic studies always focus on individual groups and it is more accurate to report directly upon what is known about these groups than to combine data with estimated totals from unstudied groups. Furthermore, by separating groups, specific gaps in knowledge are more accurately identified. In a practical sense, it is also easier and more accurate to use the finer groupings. For these reasons we subdivided many of UNEP's categories for this report.

The results of the census are presented group by group depending on the information available. Major articles and reviews are referenced, although only a fraction of the taxonomic research literature bearing on Canadian biodiversity is cited. Many thousands of titles exist, but for the most part, these would not significantly alter the known or estimated totals provided in Appendix 1.

The species diversity data presented in Appendix 1 indicate that knowledge of the taxonomy of Canadian species varies enormously from group to group. It is not surprising that the Canadian species of the larger organisms such as mammals, birds, reptiles and amphibians, higher plants, ferns, and larger and more colourful invertebrates such as the starfish, larger crustaceans, and larger insects such as dragonflies, butterflies, and grasshoppers have already been described and recorded. A comparison of total numbers in columns 3 and 4 indicates which groups are better known taxonomically. The overwhelming majority of taxonomic groups contain many species whose presence in Canada is not documented. Some groups are quite poorly known, as is explained in the footnotes to the appendix. Generally speaking, the larger the estimate of "still unrecorded" (column 4), the less precise it is. The results show that about one half of the non-viral species are not yet scientifically named, classified, and recorded in Canada. If viruses are included, the unknown level rises to three-quarters.

Generally, the smaller the animal, the

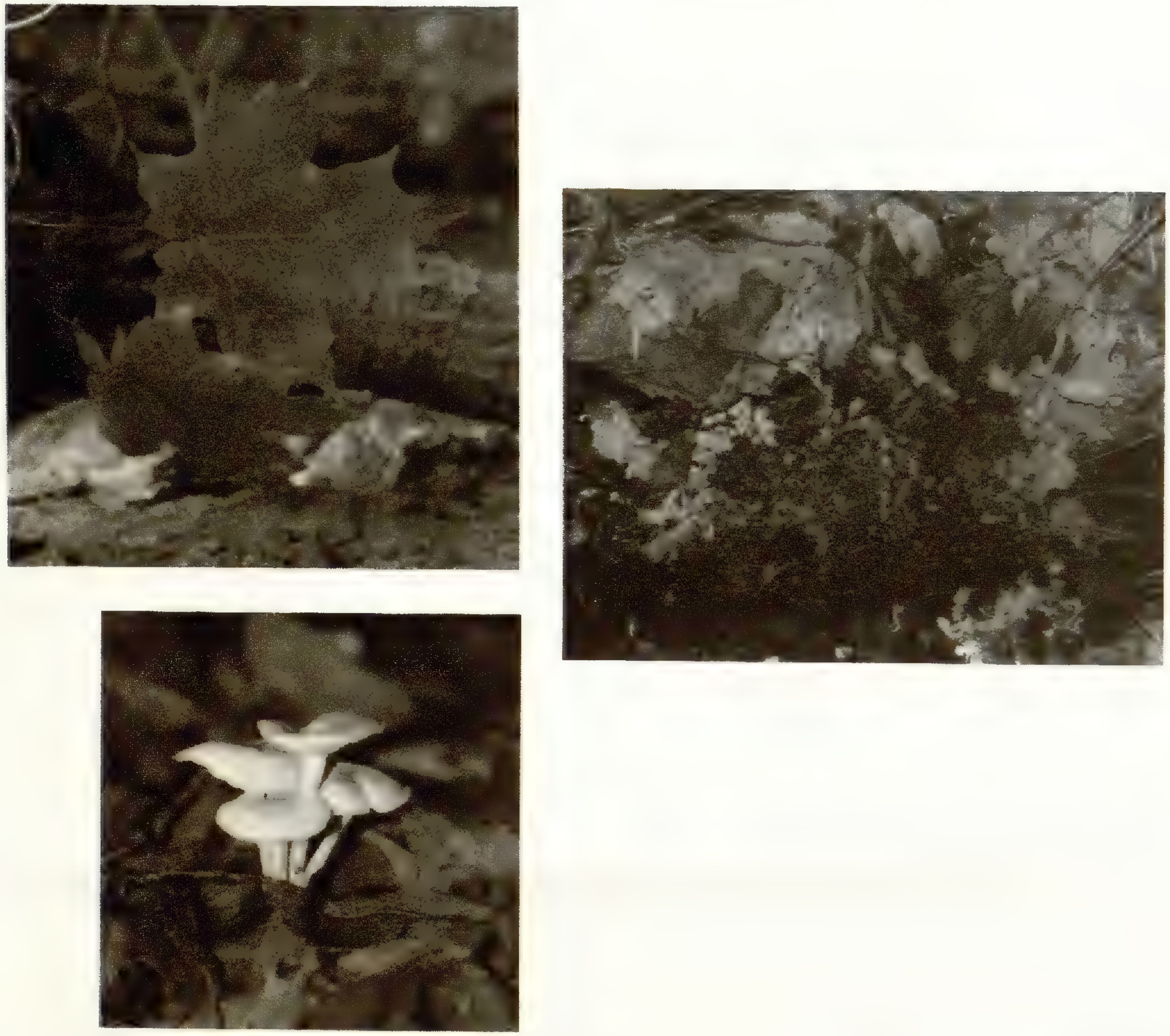


FIGURE 5

These photographs of leaves show the interconnectedness of nature. ABOVE LEFT: The leaf converts solar energy and nutrients into food for the tree. Right: The leaves fall to the ground where mites, worms, nematodes, and bacteria convert the leaf to soil elements, humus, and nutrients. BELOW LEFT: Mycorrhizal fungal filaments in the soil transfer the nutrients to the tree roots from where they move to the trunk, branches and twigs. *(photos by Don McAllister)*

less known are its species. Among the least known organisms taxonomically are the myriads of tiny free living worms and the many submicroscopic life forms living as essential symbionts or as parasites within others. The state of taxonomic knowledge for the smaller animals is particularly evident when examining the numbers of species in the various orders of insects that have been reported and that have been estimated as not yet discovered. For example, the Order Hymenoptera, which includes well known bumblebees, honeybees, wasps, ants, termites and their relatives, has 6,000 described species in Canada, but the number of unrecorded species is estimated to be more than 10,000. This is because the majority of species in this group are so small that they can scarcely be seen with the naked eye. Another reason for the high number of undescribed species is the weak support given by universities and governments to biosystematics and natural history collections. Many of these tiny Hymenoptera are referred to as "parasitic wasps", and in natural ecosystems they have a function in moderating populations of larger insects. Pesticides and other human-made chemicals are extremely toxic to these submicroscopic Hymenoptera, which have suffered catastrophic decreases in their populations (see Section 5.6) over the past two decades, and especially in the last few years. Some parasitic/predatory Hymenoptera are important in controlling pests. Other small insects and soil arachnids are also poorly understood taxonomically.

Appendix 1 reports on 65 major groups roughly at the level of phylum. Some phyla are further subdivided into classes, while the species-rich insects are divided into 25 Orders. Slightly more than 71,000 (column 3) named species have been reported in Canada. However, taxonomists estimate that the number of still unrecorded species in Canada exceeds 68,000 (column 4), again excluding viruses. This brings the grand total number of species in Canada to roughly 140,000. When viruses are included, then column 3 is increased by only about 200 species (since the taxonomy of viruses is in its infancy). However, assuming that every non-viral species can have at least one virus, the grand total of Canadian species (known, plus "still unrecorded") would double to 280,000.

Appendix 1 also includes an analysis of the sectoral ecosystem (terrestrial, freshwater, or marine) in which each group of organisms is found, as well as the percentage of species in each group found in that ecosystem (compare columns 5, 6, and 7). Where species divided their life histories between two major ecosystems, as do many insects with freshwater larvae and terrestrial adults, we split the number of species between land and freshwater. About 51% of all species in Canada are terrestrial, 23% are freshwater and 25% are marine. Insects obviously dominate in numbers of species with some 30,000 known. Some 41% of all known non-viral species in Canada are insects and the bulk of these are terrestrial.

When we analyze the major sectoral ecosystems for the distribution of phyla we obtain a very different picture. Of the 63 major phyla in this country, two-thirds are dominantly marine while one-third are dominantly terrestrial and/or freshwater (Figure 6). At a finer level, 66% occur on land, 72% in freshwater and 84% in marine regions. A similar conclusion was reported by Grassle *et al.* (1992). This indicates that taxonomic biodiversity in the oceans is more deeply seated than on lands and freshwaters, which should not be surprising considering that life originated and evolved for billions of years in brackish and marine areas. As each phylum has a very different body plan and biochemistry, this phyletic/taxonomic aspect of biodiversity is clearly significant.

The species concepts used in this census are those of professional systematists working with the various biota. In assembling species accounts, one should appreciate that the bio

PROPORTION OF SPECIES
ON LAND, IN SEA & FRESHWATER

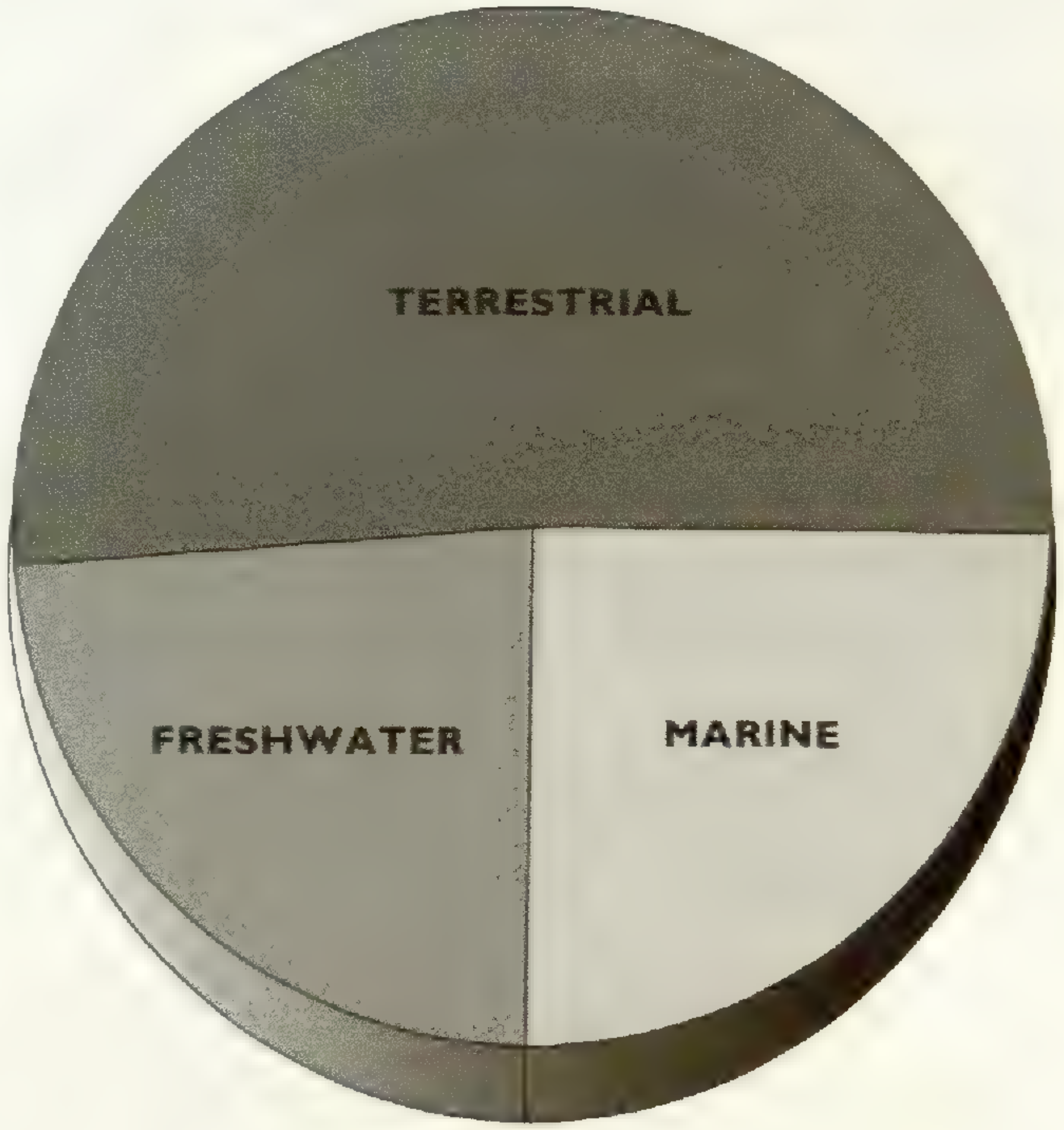


FIGURE 6

The pie chart compares the percentages of terrestrial, freshwater, and marine species in Canadian ecosystems. The chart shows that most species occur on the land. Most of those species are insects *(graph by Don McAllister)*.

logical species concept developed in higher organisms (based on the potential to interbreed) is less applicable to micro-organisms such as bacteria, whose reproductive mechanisms rely less on sex or exclude it altogether.

Following are accounts of the major groupings of organisms found in Appendix 1, with further discussion of the different and interlocking functions that the various groups of organisms play in maintaining the workings, structure and health (i.e. the norms) of the planetary ecosphere. Both time and space do not permit a full discussion of each individual phylum, class or order as presented in the Appendix. Hence, discussion of organisms follows the general groupings under the UNEP guidelines (1991).

5.1.1 VIRUSES

As noted in Appendix 1, viruses are not considered to be a taxonomic kingdom of their own. The number of virus "species" in the world, particularly viruses in the wild (i.e. those that do not infect domesticated animals, cultivated plants, or humans) is speculative since viral taxonomy and ecology is in an infant stage of study. Viruses are currently thought to be independently derived *from* the larger organisms in which they live and reproduce (i.e. from individual species of algae, plants, animals, etc.), rather than having evolved from a single common ancestor. Alternately, the host-viral similarities may be secondary, the result of adaptation to or "borrowing" from the host genome; in that case, the viruses would share a common ancestor. It is known that many plant and animal species may serve as host to one or more viruses, but scientists do not know how many viruses each host is subject to on average. Some hosts have more than one virus, as for example humans (polio; common cold; influenza; pneumonia; rabies and others). Also, some viruses (rabies is one example) can live in more than one species. Assuming a conservative average of one viral species per host species, the total number of viral species present in a country would be roughly similar to the number of host species. Based on this assumption, the number of viral species in Canada would be about 140,000.

Recent studies (Bergh *et al.* 1989; Suttle *et al.* 1990; Olofsson *et al.* 1991) have shown that free-living virus populations may be extremely dense in warm marine and fresh waters, suggesting that viruses may play significant roles in these natural ecosystems, possibly in the regulation of population explosions or "blooms" (i.e. function 5 of Table 2) in these ecosystems. The surprising abundance of free viruses may indicate some as yet unknown ecological function.

5.1.2 BACTERIA (KINGDOM PROCARYOTAE)

The taxonomy of bacteria is evolving rapidly due to new techniques of gene analysis. About a decade ago, two major groups were recognized: the "true bacteria" and the "cyanobacteria" with the latter sometimes called "blue green algae". Hence separate estimates are provided for these two groups in Appendix 1. However, bacteria are now proving to be so diverse that they are being subdivided into a large number of phyla under the kingdom Procaryotae. The phyla suggested by Margulis and Schwartz (1988) are provided in Appendix 1. These underline the diverse nature of bacteria. Separate taxonomic estimates of species numbers in these phyla are not yet available, but the total numbers and the diversity may prove to be several magnitudes higher than currently known or believed.

The occurrence, abundance, and distribution of Procaryotae in natural ecosystems has received only passing interest from taxonomists and ecologists. Hence, little information on bacterial species and numbers in natural systems is available. In soils, however, bacteria are the most numerous group of micro-organisms, with between 10 million and 100 million individuals per gram and several billion per handful. Many bacterial groups require highly specialized habitats (i.e. hypersaline conditions, hot sulphureous water, anaerobic conditions, symbiontic/conditions etc.), suggesting that they would be present only where suitable ecosystems or hosts occur. Some are found deep in rock strata.

The ecological and economic importance of Procaryotae has been grossly underestimated. It is now realized that bacteria play a large number of surprising and determining functions in shaping ecosystems and the ecosphere. In this regard Margulis and Schwartz (1988), Bergey (1983-1989), Austin (1988) and some others have identified the following 14 basic ecological functions of bacteria:

1. primary production (in both anaerobic and aerobic conditions), which means that they are primary producers for protozoa and support major food chains;
2. converting organic molecules (e.g. in marshes, sewage plants) into methane;
3. controlling populations of animals and plants ("diseases");
4. reducing sulphur to produce gaseous sulphur compounds in sediments and water—essential for the formation of all proteins;
5. reducing organic phosphorus to inorganic in aquatic ecosystems;
6. forming major symbiotic relationships with plants and with both marine and terrestrial animals;
7. fixing nitrogen from the air both freely and symbiotically by living within living tissues of other organisms;
8. producing biomass from purely inorganic compounds (the pseudomonads);
9. oxidizing methane (in bogs, fens), nitrogen and sulphur;
10. hydrolyzing large complex molecules such as polysaccarides, nucleic acids, cellulose and fatty acid eters;
11. fermenting almost any organic molecules;
12. producing many kinds of antibiotics;
13. producing light (bioluminescence); and
14. precipitating iron, gold and other metals.

The transfer of genes to bacteria (or among bacteria), using genetic engineering techniques, now enables scientists to reproduce organic compounds, including those of use in pharmaceutical and other industries. Biotechnology may reduce the need to extract compounds from species in the wild and thus make it more feasible to retain wild species and ecosystems in their more normal state. One example of such a transfer, which appears to have "eco-friendly" consequences and which may be economically attractive, is described in a review by McAllister (1992). Here a new bacterium has been engineered to complete fermentation—breaking down cellulose to sugars then converting them to alcohol. In this case almost any kind of plant material, including paper mill sludge, can be used for the production of ethyl alcohol (a relatively benign natural compound).

The UNEP Guidelines (1991) suggest that there might be 3,000 species of bacteria in the world. However, according to Murray (1989), who was closely associated for many years with the production of the Bergey's Manual of Bacteriology (Bergey 1983-1989), the Canadian total is closer to 20,000, but it may be many times that number. Apparently, many bacteria have global distributions, which is not surprising considering that they are tiny enough to be transported in many ways through world travel and transport of agricultural and industrial products through trade. Others cannot be cultured outside their natural environment and hence are extremely difficult to find or study.

The photosynthetic bacteria, recognized in Appendix 1 as Cyanobacteria and Chloroxybacteria, are very small and unicellular but some may form thread-like strands. Canadians are becoming more familiar with these organisms because of brilliant green blooms appearing on the surfaces of overfertilized rivers and lakes across the southern parts of the nation where abnormally high inputs of nutrients from human activities occur.

The photosynthetic bacteria play major ecological functions throughout the world in terrestrial, freshwater and marine ecosystems. Because of their high abundance in marine systems, they produce enormous biomass and most of the world's oxygen. As well, they provide the essential base for marine food chains worldwide. Many species fix nitrogen and are symbiont partners, as for example in lichens, ferns, and mosses, thus providing nitrogen fertilizers over boreal and arctic regions of Canada. Many cyanobacteria have the capacity of metabolizing hydrocarbons such as petroleum compounds and reducing them to more harmless substances and hence have a very significant decomposition function.

Dr. Frances Pick of the University of Ottawa suggests that perhaps 1,200 cyanobacterial species occur in Canadian waters and soils, on mosses, tree trunks and detritus. Perhaps 800 of these remain undescribed or unreported for Canada, attesting to the small effort in taxonomic research to date. The almost non-existent support for taxonomic and ecological research into naturally occurring bacteria is surprising considering their critical functions in natural ecosystems and the obvious economic implications of these functions.

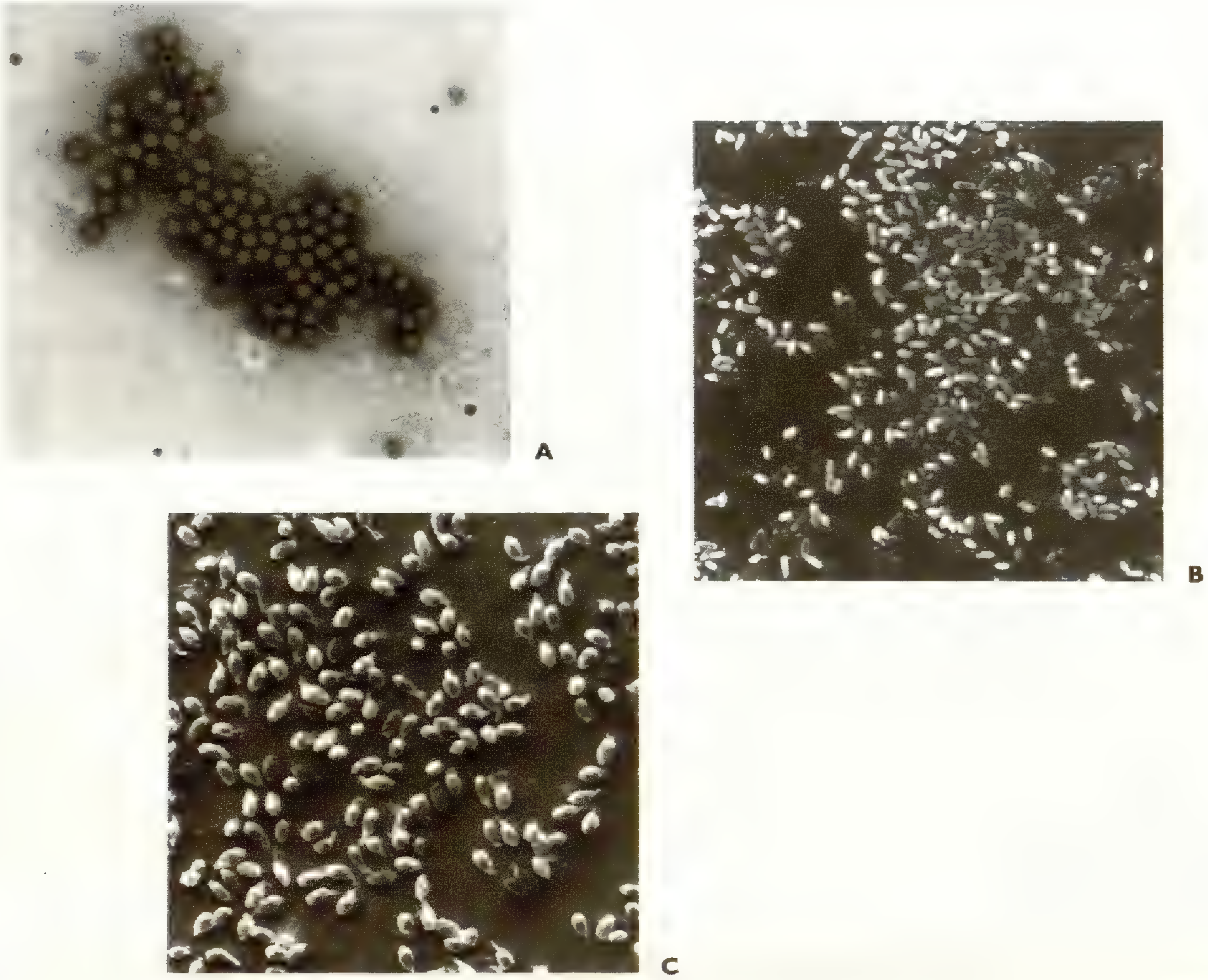


FIGURE 7

A) A Negatively stained electron microphotograph of *Reovirus*. The virus particles, approximately 65nm in diameter have a definite cubic symmetry. The particles with black centres are "incomplete"; they do not contain nucleic acid. B) A scanning electron microphotograph of the bacterium *Bacillus subtilis*. This particular organism is rod-shaped; other bacteria have coccoid, filamentous or spiral shapes. The shape of bacteria is used as a primary tool for their classification. C) The spores of *Clostridium sporogenes* seen in the scanning electron microscope. Spores are highly resistant to adverse external conditions; they contain all of the genetic material of the original cell and permit survival of the organism until the external environment becomes beneficial for its vegetative growth *(microphotographs courtesy of Dr. Syed A. Sattar, Department of Microbiology, University of Ottawa)*.

5.1.3 ALGAE AND PROTOZOANS (KINGDOM PROTOCTISTA)

While 27 phyla of Protoctista are recognized by Margulis and Schwartz (1988) for the world, only 10 phyla of algae plus only one of "protozoa" are recognized in this Canadian census. It would take a major effort to attempt to estimate the numbers of species in all 27 phyla since pre-existing taxonomic literature does not use the 1988 classification.

Again, it is easier and more accurate to secure estimates of species numbers from taxonomists when one deals with small taxonomic units (i.e. avoids lumping of phyla, classes, etc). The ecological roles played by algal groups in creating the ecosphere as we know it and in primary production is immeasurable, although it is known for example, that photosynthesis by algae (and cyanobacteria) in the world's oceans produces a large portion of the world's oxygen (Raymond 1980; Parsons *et al*. 1984; Round 1985).

The ecological and economic importance of the diverse kinds of algae (along with cyanobacteria) is grossly underestimated, particularly as these provide the underpinnings of marine and freshwater food chains. The free ecological work of these primary producers provides the essential foundation for life in oceans and some fresh waters. Yet, algae are simply taken for granted, as attested to by the fact that in Canada not a single book describes the taxonomy, distribution, and ecology of freshwater species and their role in food chains. In addition to the functions of primary production and oxygen production of single-celled algae, some algal phyla develop large three-dimensional structures (function 14 of Table 2). Such algae create essential living space, cover and nurseries for a rich variety of marine and freshwater life. These include particularly the brown, red, and green algae in marine shorelines and the charas and macro green algae in freshwater lakes and rivers. Some functions other than primary production and oxygen production of different algal groups are listed in Appendix 1.

The totals of algal species reflect the current state of taxonomic knowledge. Again this varies according to phylum. The phyla with large, multicellular species (brown, red, and green algae) are generally better known taxonomically, since expensive equipment is not as essential for the conduct of basic taxonomic descriptions and inventories.

Protozoans are one of the most important "grazers" of bacteria. They are more or less ubiquitous in moist and watery environments and often extremely abundant as part of the biomass. They transform the immense productivity of bacteria into "plaque" forms that are then eaten by hosts of protozoan zooplankton in both aquatic and terrestrial systems. Protozoa also derive their food from detrital particles of all sorts. Hence, they play key roles in providing a base for food chains. In the oceans many protozoans have calcareous skeletons and upon death their shells rain down upon the ocean floor to create the thick deposits of marine limestone (Section 4.7). Their capacity to precipitate carbon dioxide is a globally significant ecological function.

Notwithstanding their ecological functions, little or no taxonomic research into protozoan species or genera seems to be taking place in Canada today, and as well their taxonomy elsewhere is undergoing radical changes due to new genetic research techniques (Margulis and Schwartz 1988; Brusca and Brusca 1990). Hence, the suggested number of Canadian species, namely 1,000, is a guess, based upon outdated literature and the large suggested number of species globally. The protozoa are ranked among the most difficult of taxonomic groups and this may be one of the reasons they have been neglected by researchers.

5.1.4 FUNGI (KINGDOM EUMYCOTA)

The number of species of fungi in the world has now been estimated by Hawksworth (1992) to be 1.5 million, making this the

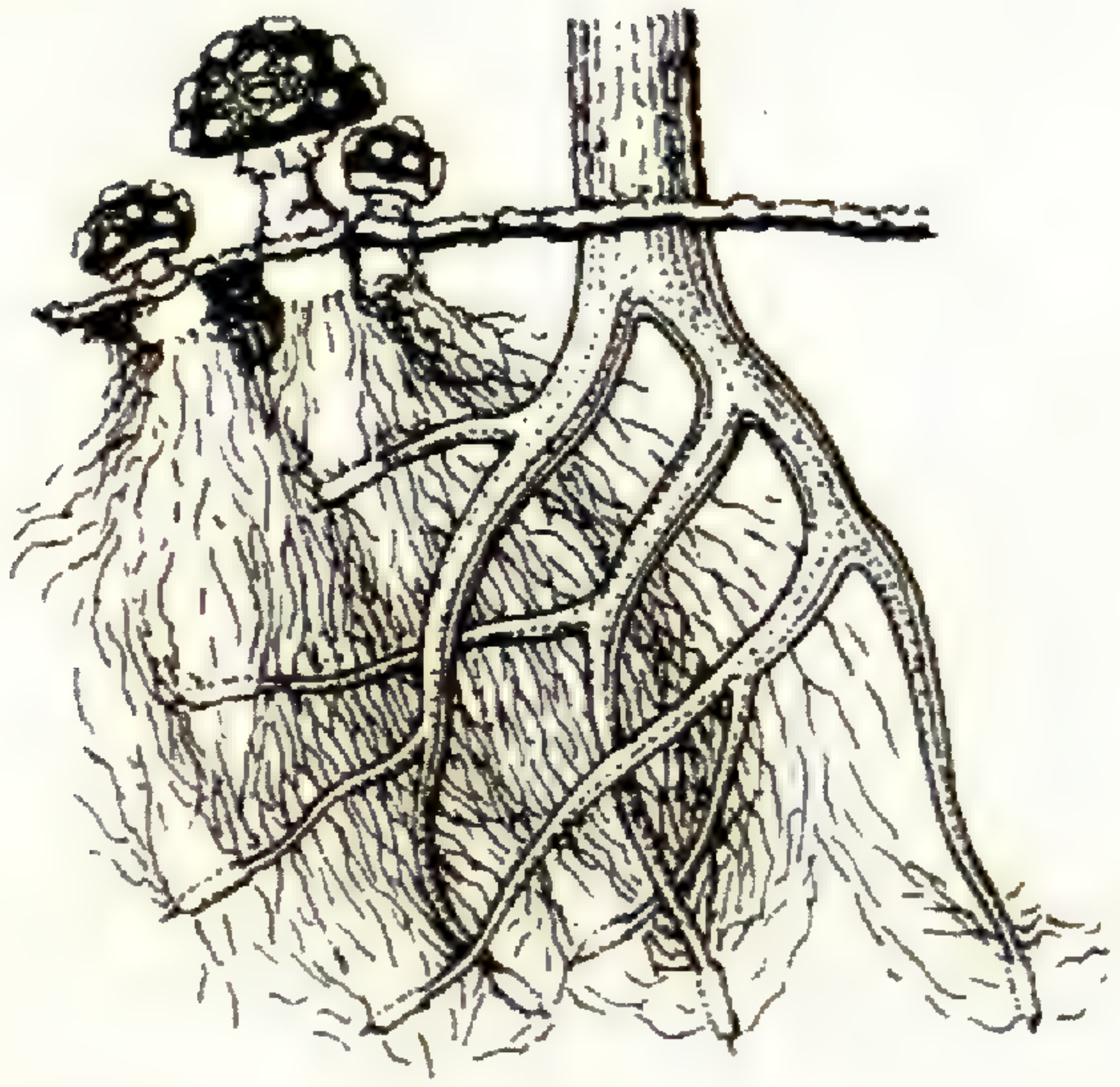


FIGURE 8

Mycorrhizal fungal partnerships are important between fungi and 75% of vascular plants. The myco fungus network may supply much of the nutrients and some of the moisture needed for healthy growth in coniferous trees. The network beneath a single conifer, placed end to end, may be long enough to reach around the earth five times. *(illustration by Roelof Idema, courtesy of* Global biodiversity)

largest phylum of living things next to the arthropods. In Canada, where mycological research has a long tradition, the number of species recognized and described is 11,310 (in six phyla). Nevertheless, perhaps a third of this number remain unrecorded, due mainly to the complex nature of fungal relationships with hosts of other organisms (Cherfas 1991; Hawksworth 1991a, 1991b, 1992; Read 1993), and the low level of support for studies of the species involved in such relationships.

Largely unrecognized by current forestry management and farming practices (Ditchfield 1993), certain fungi form vital partnerships (called mycorrhizae) with the roots of trees, shrubs, grasses, and other plants. These fungal partners (symbionts) affect the absorption of nutrients in an estimated 80% of seed plant species, enhancing their growth and may protect against infection by other harmful fungi. The total length of the mycorrhizal network under an average mature tree has been estimated as six times the circumference of the Earth (McAllister 1993b).

Better understanding of mycorrhizal taxonomy and ecological functions could lead to an appreciation and enhancement instead of destruction of these key partnerships in farming, forestry, and recognition of the case for their retention in the wild through appropriate management. For example, the widespread use by government agencies and the forest industry of herbicides as a control for broad-leaved shrubs and trees is occurring in near total ignorance of the short- and long-term impacts upon the many kinds of symbiotic relationships between and among organisms found in normal forest soils.

Fungi are major recyclers of terrestrially produced carbon (function 13, Table 2) as they have the capacity to degrade lignin and cellulose (Seifert 1992). They are essential symbionts in rumens of cattle, bison and the like. They also act as moderators of populations of many species, affecting both plants and animals.

Acid rain and the use of chemical fertilizers and pesticides appear to be at the root of the impairment of the ecological functions of fungi (Hawksworth 1992; Cherfas 1991; Hammond 1991; Browning & Hutchinson 1991), in both terrestrial and freshwater ecosystems. The case of declining lichens (and the loss of functions performed) in eastern Canada is described in Section 5.5 below. Overharvesting and the marketing of edible and hallucinogenic fungi on the West Coast appears to be contributing to their decline. Clearcutting and slash-burning further contribute to that decline (Harvey *et al.* 1980).

5.1.5 HIGHER PLANTS (KINGDOM PLANTAE)

The UNEP guidelines lump the "higher" plants into one category, Plantae. Included here are bryophytes, lycopods, horsetails, ferns, conifers, and flowering plants. Together they are the great primary producers of terrestrial ecosystems, providing the food base for almost all terrestrial animal life. Their three-dimensional structures are the basis for an enormous range of macro- and micro-habitats in which other species live and shelter, both above and below the ground. There are about six land animals for each species of land plant in Canada. The plants provide much of the habitat, and are the primary ultimate source of the food for these animal species.

In comparison with almost all other major groups of organisms, the basic taxonomy of species in these groups is well-known. Distributional data in space and time are often imperfect, but the true role (food, shelter, living and nesting places for other species of the forest, tundra, prairie, or dryland) of plants in maintaining the normalizing functions of ecosystems remains largely unstudied.

New additions to the Canadian flora usually refer to exotics introduced from other parts of the world or to geographical variants of more widely distributed species.

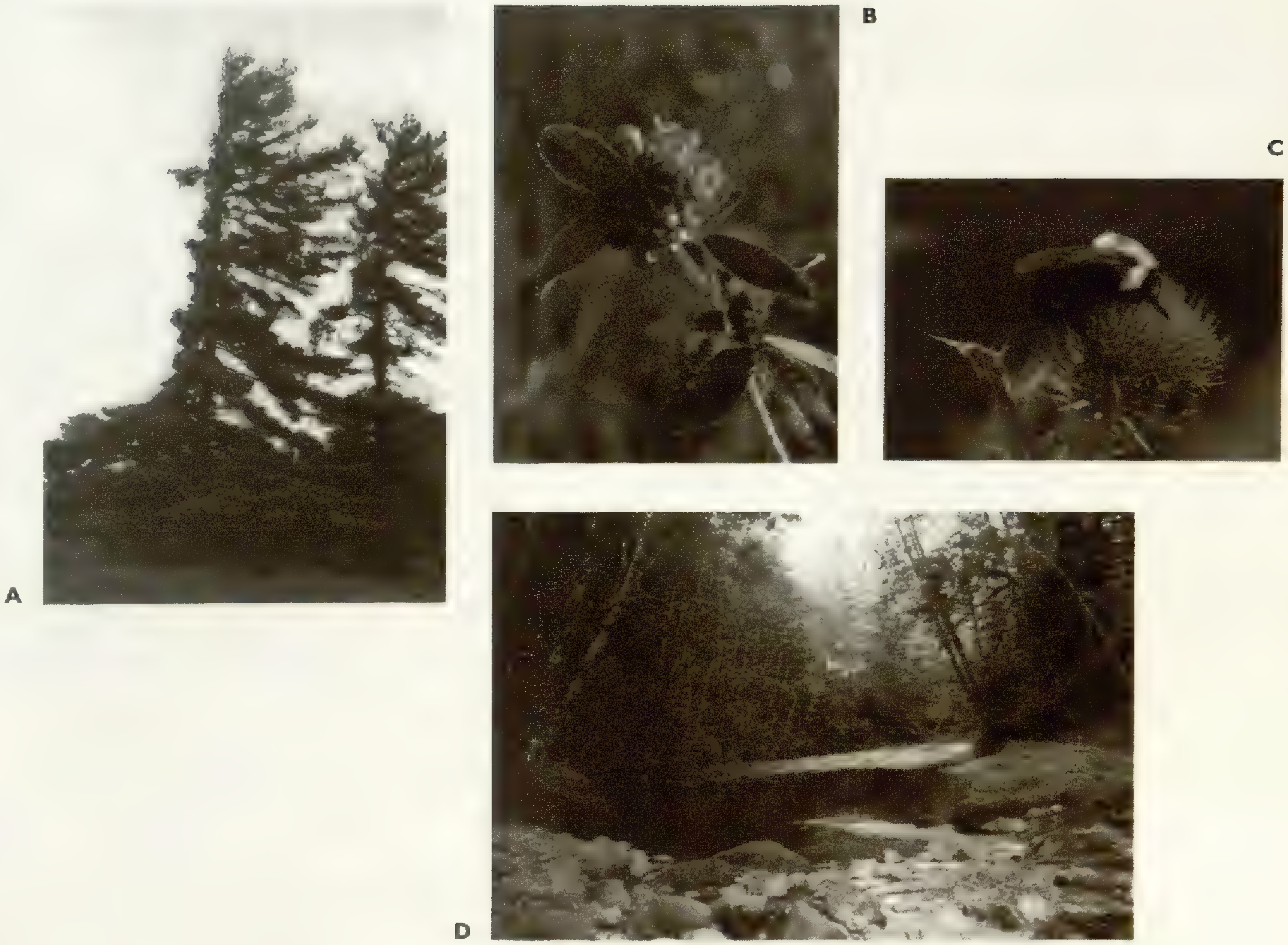
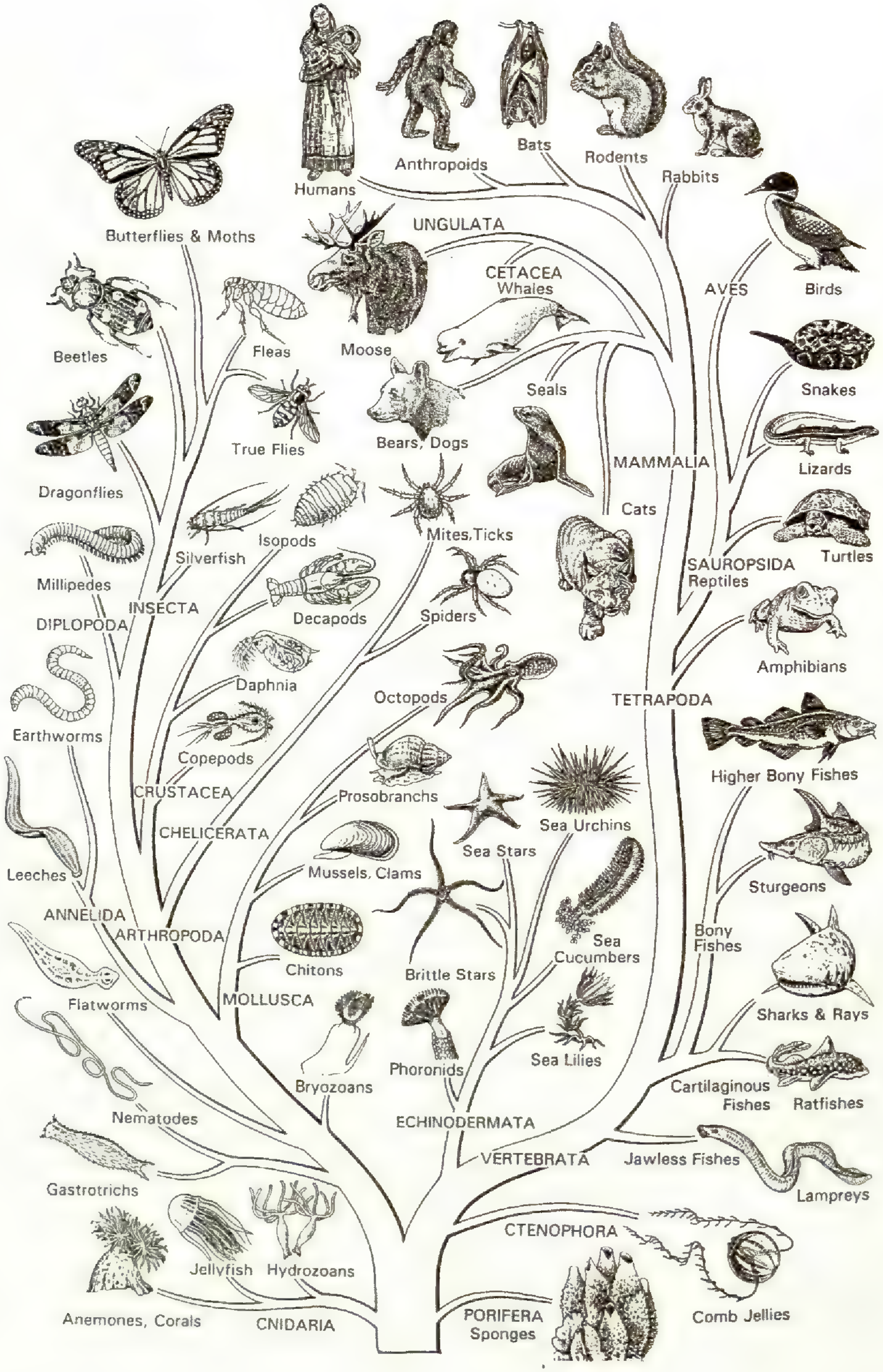


FIGURE 9

Illustrations of 4 ecological services: A) carbon banking by trees reduces greenhouse gas based global warming; B) nitrogen fixation by clover, legumes, and other species provides an essential nutrient for other plants; C) pollination by insects produces viable seeds, sets berries and fruits, and enhances genetic diversity; D) vegetation moderates the hydrological cycle, reducing rapid runoff and flooding. *(Photos A, B, and D by Don McAllister. Slide C by Ted Mosquin.)*

MAJOR ANIMAL GROUPS IN CANADA



Humans
Anthropoids
Bats
Rodents
Rabbits
Butterflies & Moths
UNGULATA
Moose
CETACEA
Whales
AVES
Birds
Beetles
Fleas
Seals
Snakes
True Flies
Bears, Dogs
Dragonflies
MAMMALIA
Lizards
Cats
Silverfish
Isopods
Mites, Ticks
Turtles
SAUROPSIDA
Reptiles
Millipedes
Decapods
Spiders
DIPLOPODA
INSECTA
Amphibians
Daphnia
Octopods
TETRAPODA
Earthworms
Copepods
Higher Bony Fishes
CRUSTACEA
Prosobranchs
Sea Urchins
CHELICERATA
Sea Stars
Leeches
Mussels, Clams
Sturgeons
ANNELIDA
ARTHROPODA
Sea Cucumbers
Bony Fishes
Chitons
Brittle Stars
Flatworms
MOLLUSCA
Sharks & Rays
Sea Lilies
Phoronids
Bryozoans
Cartilaginous Fishes
Ratfishes
Nematodes
ECHINODERMATA
VERTEBRATA
Jawless Fishes
Lampreys
Gastrotrichs
CTENOPHORA
Jellyfish
Hydrozoans
Anemones, Corals
CNIDARIA
PORIFERA
Sponges
Comb Jellies

FIGURE 10

Family tree of animals, showing the wealth of larger and smaller animals that have evolved in the last 3.5 billion years (*adapted from Smithsonian chart by Roelof Idema*).

The major unknowns about the ecology of the higher plant groups concern their intricate interdependencies with various other symbiotic organisms (e.g. bacteria, fungi, algae, pollinators, etc.) with which they evolved. One useful observation is that soil biota represent a largely unstudied realm. Yet, it is in the soil that roughly half of each plant grows. In grasslands more than four-fifths of the plant's weight can consist of roots; in forests, one quarter (Davis *et al.* 1992). Under a single square metre of grassland one might expect 40 km of roots; under 2.5 hectares, a million km of roots (McAllister 1993c).

5.1.6 ANIMALS (KINGDOM ANIMALIA)

The Kingdom Animalia includes the "non-protozoan" invertebrate and vertebrate animals that are generally familiar to students of biology and informed people. These larger herbivores, omnivores, and carnivores range enormously in size, in basic body structure and function, and in the specific roles they play in ecosystems.

There is an extensive literature on vertebrates and insects. The taxonomic literature on aquatic invertebrates in Canada is summarized by Sharma *et al.* (1983). Reviewing this literature is a formidable task and requires the attention of specialists.

No animals are primary producers; all must obtain food either directly from photosynthesizing cyanobacteria, algae or higher plants, secondarily by eating herbivores, by absorbing or ingesting the detritus of life either as molecules through their skin (only two phyla live this way) or through directly ingesting of organic detrital particles or eating live or dead animals. Some of them, like sea anemones, reef-building corals, and bioluminescent marine organisms depend upon symbiotic partnerships with bacteria.

5.2 CONSERVATION STATUS OF SPECIES AND POPULATIONS BY CATEGORY

Canadian species and unique populations fall into a number of distinct categories under which their survival status is discussed below.

5.2.1 EXTINCT, THREATENED AND VULNERABLE SPECIES

Appendix 2 reviews the status of Canadian species, subspecies, or unique populations known to be extinct, extirpated, endangered, threatened, and vulnerable. The list is based upon reports prepared for, reviewed, and approved by the Canadian Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC was established in 1977 and includes representatives of federal,

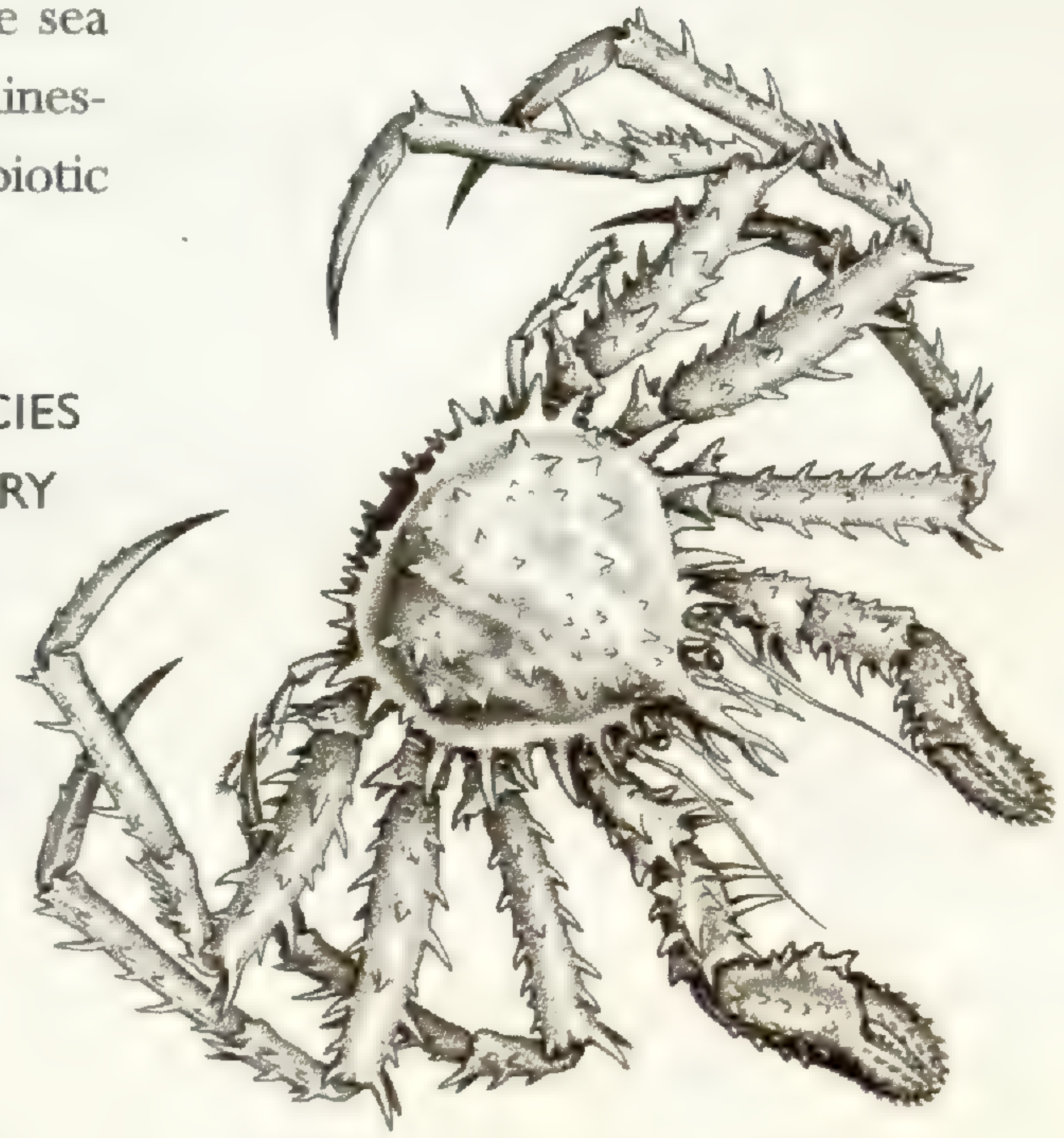


FIGURE 11

Troll crab, an example of deepwater marine organism found on the Atlantic coast of Canada. Recent estimates, contested by some scientists, have suggested that the deep sea may be home to as many as 10 million species, a much higher estimate than was previously assigned (*illustrated by Roelof Idema, courtesy of* Global biodiversity).

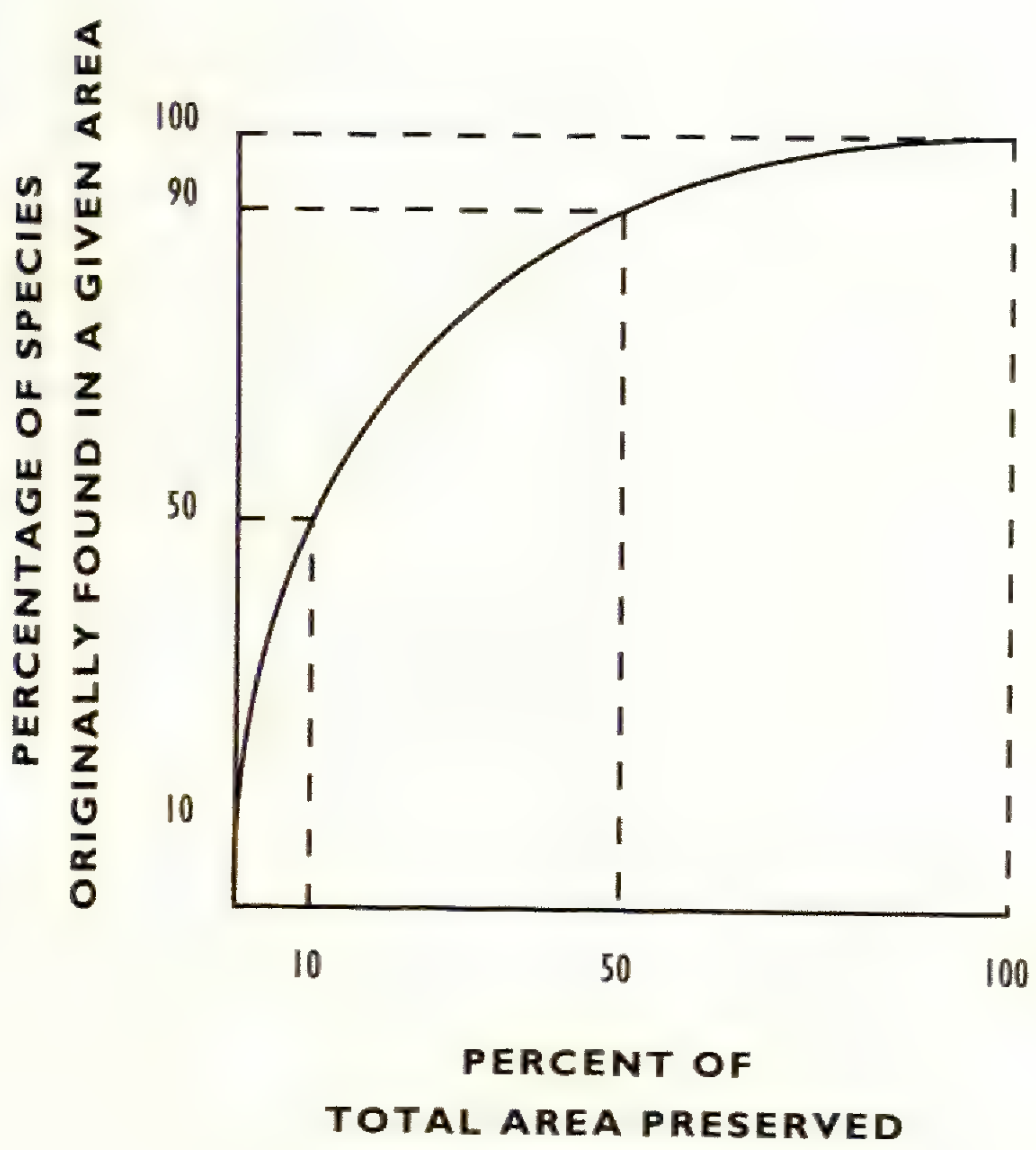


FIGURE 12

The logarithmic species-area curve shows the importance of area to the survival of species and to allocating sufficient protected areas on land and sea. The curve shows that if an area is cut by 90%, then 50% of the species will disappear. On the other hand, the relationship between many ecological services and area is close to linear; when 90% of a forest is clearcut and slashburned to bare soil, the oxygen production, carbon-fixing and structural habitat support is cut by 90%, until such a time as equivalent regeneration of the ecosystem has taken place.

provincial and territorial governments, and national environmental organizations. Activities of COSEWIC are complemented by the Committee on the Recovery of Nationally Endangered Wildlife (RENEW) established in 1988 for the purpose of promoting, orchestrating, and accounting for the recovery of wildlife species that are nationally at risk (Dauphiné 1989; Prescott and Aniśkowicz 1992; RENEW 1990).

COSEWIC's findings are published in the form of detailed status reports on individual species and made available to the public. Since its inception, the Committee has evaluated some 300 species (an average of 17 per year) of which 236 have been assigned national status (COSEWIC 1994) in the categories noted in the above paragraph. The number of Canadian species still to be reviewed by COSEWIC is very large because dozens of major animal and plant groups are known to contain rare species whose status is currently unstudied. For example, the occurrence and distribution of rare vascular plants of Canada have been studied by Argus and Pryer (1989). They report that out of the 3,269 native Canadian species reported by Scoggan (1978-79), 1,009 are rare. This is 31% of the native vascular plant flora. Of the rare vascular plants, only 64, or less than 7%, have received designation by COSEWIC; the status of all the rest may be subject to review. The status of the large proportion of reptiles and amphibians, many of which are rare, likewise remains unverified by COSEWIC. The same is true of the bony fishes where of the 1,091 species known to occur in the country, only 53 have had their status determined by COSEWIC, while it is estimated that perhaps an additional 150 species, or 14% of the entire fish fauna, may be deserving of designation by the Committee (McAllister 1985, 1990, 1992; McAllister and Gruchy 1977). In considering these totals it is worth bearing in mind that COSEWIC does not currently evaluate the status of any invertebrates, algae, fungi, etc., and neither are funds available to do so. Only vertebrates and vascular plants are included in status reports. Prescott and Aniśkowicz (1992) have made some suggestions for enhancing the COSEWIC and RENEW processes.

It should be emphasized that the status of vulnerable, threatened, and endangered attributed by COSEWIC confers no legal protection, although it has a certain moral force. In this regard the listing of a species differs from the U.S. Environmental Protection Act which stringently protects listed endangered species and their habitat.

Documented extinctions of Canadian species, subspecies, and unique populations began immediately following the arrival of Europeans during the late 18th century. Many were caused by commercial exploitation. The known extinctions/extirpations include the Great Auk, Passenger Pigeon, Labrador Duck, Banff Longnose Dace, Blue Walleye, Deepwater Ciscoe, Longjaw Ciscoe, Sea Mink, Blue-eyed Mary, Illinois Tick Trefoil, the Greater Prairie Chicken, the Gravel Chub, Paddlefish, Gray Whale (Atlantic population), Walrus (northwest Atlantic population), Black-footed Ferret, Plains Grizzly and the Swift Fox. In considering these extinctions and extirpations, one has to bear in mind that associated species (e.g. parasites, pollinators, fungi) may also have become extinct along with their hosts. Furthermore, records do not exist for the large numbers of invertebrates, algae, fungi, and micro-organisms whose populations have been drastically affected over the past 250 years.

The number of today's endangered, threatened, and vulnerable species reflects the continuing incremental loss of habitat over extensive regions of Canada. The areas of Canada where rare species, subspecies and unique populations are most vulnerable today are southwestern Ontario, the southern prairies, and the dry lowland valleys of interior southern British Columbia. All these

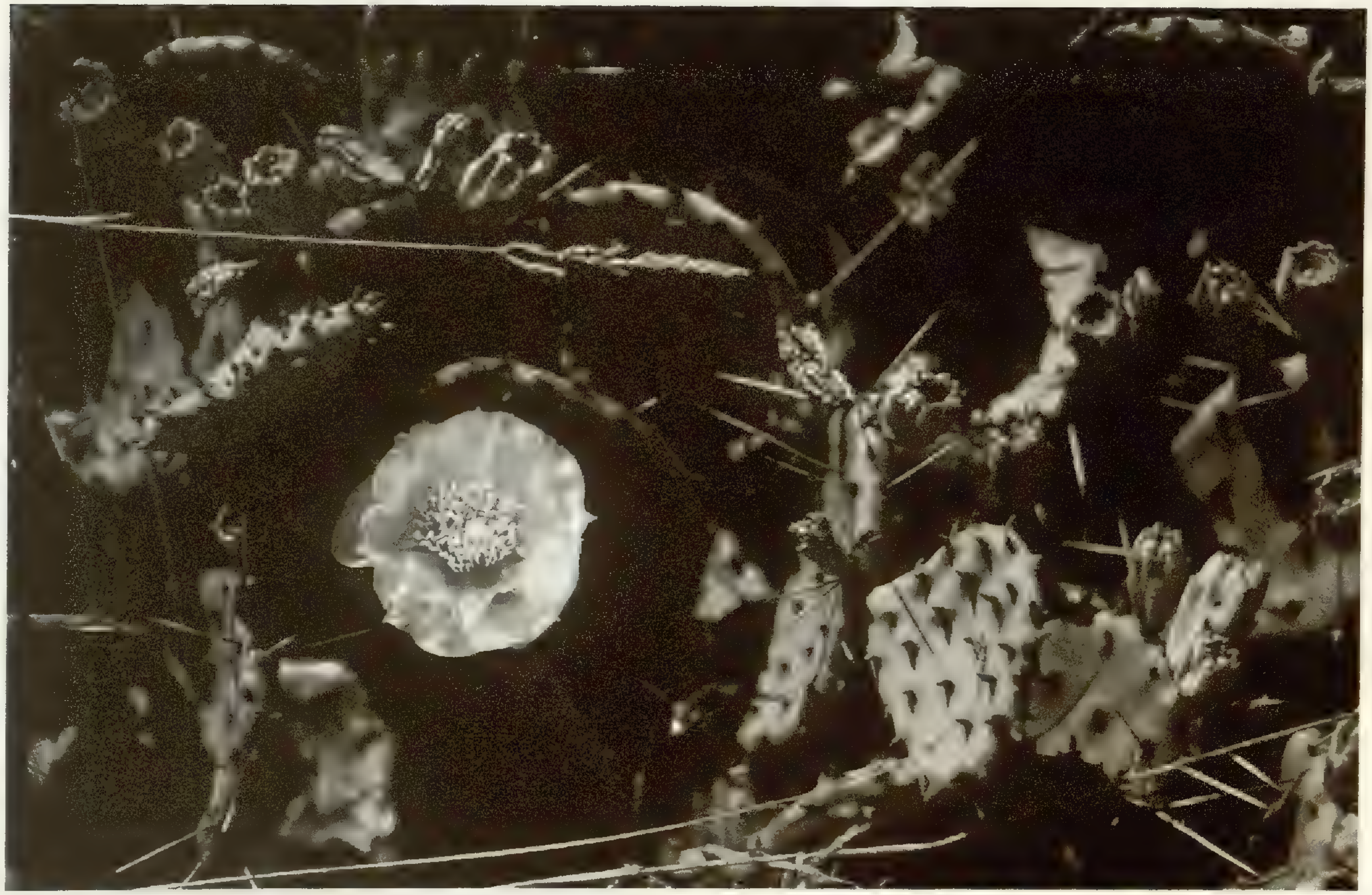


FIGURE 13

Eastern Prickly Pear Cactus, *Opuntia humifusca,* one of Canada's endangered species. It survives in Canada only in Point Pelee National Park, Pelee Island, and at one location in Kent County, Ontario. Applying the percentage from well studied groups it is estimated that there are at least 8,000 species of concern in Canada vulnerable, threatened, endangered, extirpated, or extinct (*photo by Ted Mosquin*).

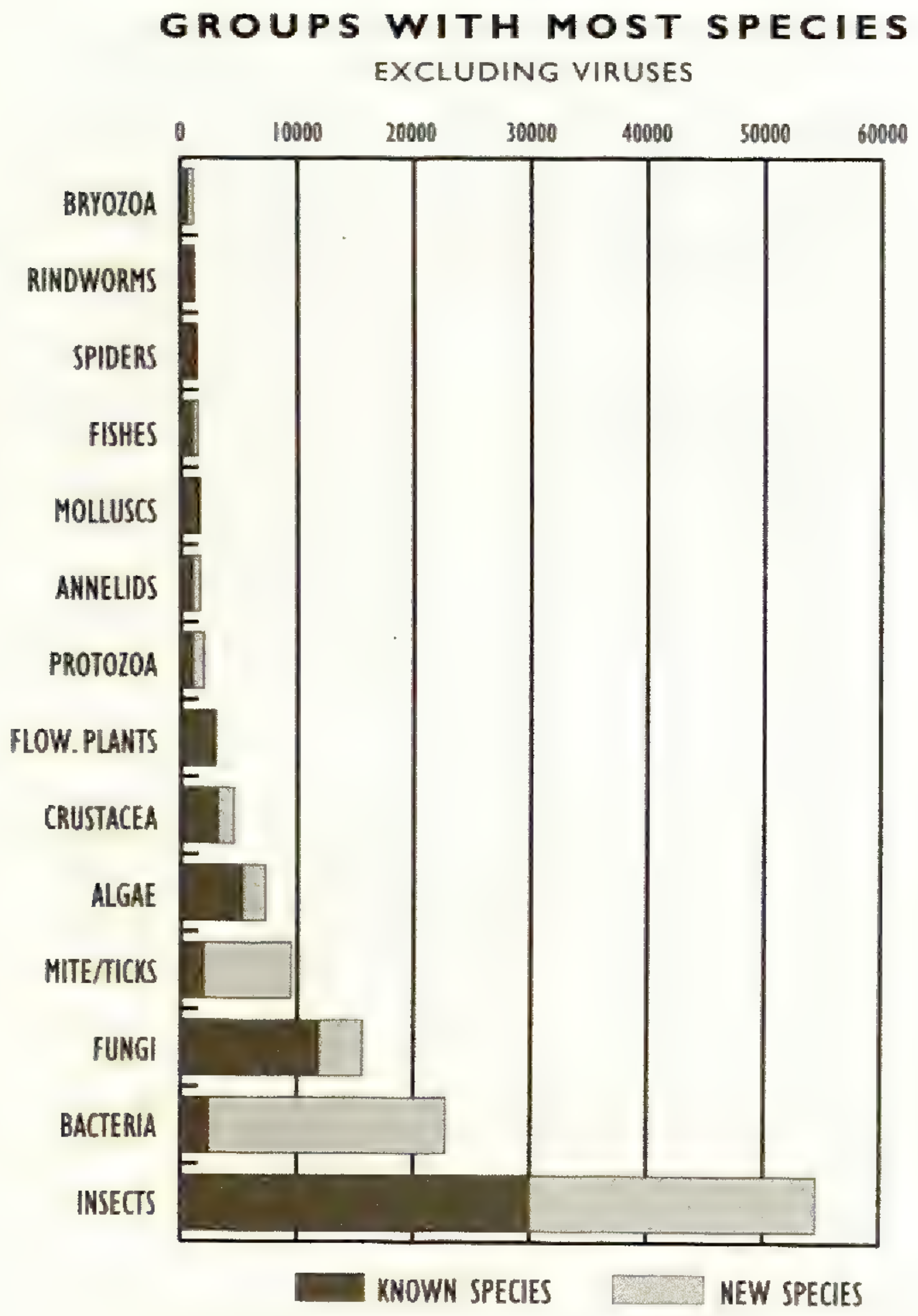


FIGURE 14

The taxonomic groups with the most species in Canada are graphed above. Although the larger-sized species like birds and mammals are better known, the groups with small sizes often have more species and play key ecological roles such as pollinating flowers, pest control, recycling nutrients, etc. The numbers in the graph show total counts for those already named scientifically and new species not yet named (*graph by Don McAllister*)

areas are subject to intensive urbanization and agriculture. These southern parts of Canada also contain the richest biodiversity (Clarke 1981; McAllister 1985; Argus and Pryer 1989; Schueler and McAllister 1991; Burnett *et al*. 1989). As well, clearcut logging in areas of British Columbia and some other provinces is reducing biodiversity locally and regionally and affecting rare species.

Clearcut logging is particularly destructive of normal ecosystems when it combines clearcutting of all standing trees (regardless of age and sometimes on steep slopes with attendant mass erosion of soils and siltation of streams) with intense fires that burn off the “debris” branches and decaying wood along with much organic topsoil with its diverse assemblages of microflora and fauna, understorey plant species, and seeds and roots. This method of forestry eliminates or reduces subterranean fungal systems upon which trees depend for nutrients (Harvey *et al.* 1980; Hawksworth 1991; Hammond 1991). Since lowland old growth canopies now occupy only a small shrinking percentage of west coast rain forest, there is ever less habitat for the rare Spotted Owl, the Marbled Murrelet, and possibly for other as yet unknown canopy-requiring species. It is for this reason that study of the insect fauna in canopies of these remnant old growth rainforests by the Western Canada Wilderness Committee was recently initiated using canopy walkways. It is estimated that there are 500 to 600 still undescribed species in the temperate rainforest canopy.

5.2.2 ENDEMICS: SPECIES, POPULATIONS AND GENES

The concept of endemism is important when discussing the biodiversity of a nation. Canada provides habitat for many species, but relatively few of these are endemic to this country (i.e. found nowhere else). This is in fundamental contrast to the biodiversity of warmer regions of the world, which are frequently rich in localized endemics. The exact overall proportion of endemic species in Canada is unknown, but probably lies between the 1%- 5% level for most taxa.

Examples of Canadian endemics include 28 species of plants from the Yukon (Argus and Pryer 1989); a white flowered, self-pollinated form of wild flax, *Linum lewisii*, ssp. *lepagei*, from the Ontario shores of James Bay (Mosquin 1971b); the Vancouver Island marmot, *Marmota vancouverensis*; a blind subterranean amphipod, *Stygobromus canadensis*; from Castleguard Cave, Banff National Park, Alberta; several plant species in the Lake Athabasca sand dune region of northern Saskatchewan (Argus and Pryer 1989; Burnett *et al*. 1989); an oligocheate worm, *Henlea yukonensis*, (Tynen *et al*. 1990) from an unglaciated area in the Yukon; the copper redhorse, *Moxostoma hubbsi*, from the Montreal area of Quebec, and the Acadian whitefish, *Coregonus huntsmani*, from southern Nova Scotia (McAllister 1992).

The low degree of species endemism reflects three factors. First, the series of Pleistocene glaciations that culminated in the last, or Wisconsin, glaciation probably eliminated many localized Canadian endemic species. McAllister *et al*. (1986) found that high densities of localized North American endemic freshwater fishes were found only about 3° south of the northern edge of the drift-free zone in the United States. The clustering of Canadian endemics in or near known glacial refugia also supports this hypothesis (see below). Second, in many groups of plants and animals, there is an increase in the numbers of species towards the equator; we suspect that there is a corresponding increase in the numbers of endemics. Third, many species occurring in Canada are wide-ranging, and those ranges often cross south into the U.S., westward into Alaska, or eastward into Greenland. This means they are not technically endemic to Canada, even if most of their range is Canadian. Canada's arctic marine species, judging by the fishes, are often shared with Alaska, Russia, or Greenland (McAllister 1962). Similarly, many species of the Canadian North Pacific and North Atlantic range south into the U.S., or respectively west to Asia or east to Europe.

The known number of Canadian endemic species is increasing. In part, this reflects more refined taxonomic studies that reveal subtly distinguished species in well-studied groups, or new species in one of many groups that are inadequately studied.

Canadian endemics are often associated with glacial refugia—unglaciated areas in which plants and animals survived glaciation and from which they often dispersed following glaciation. Notable refugia for Canadian biota include: Beringia (parts of Siberia, Bering Strait, Alaska, and the Yukon); Washington State; in the northern United States, Mississippi and Missouri basins, New England and southwards. Evidence for other smaller Canadian refugia is accumulating. These include the Banff/Jasper refugium in the Alberta foothills of the Rockies (Crossman and McAllister 1986), the Queen Charlotte Islands (Calder and Taylor 1971), the Richardson Mountains in the Yukon (Tynen *et al*. 1991), southern Vancouver Island, and southern Nova Scotia (Burnett *et al*. 1989).

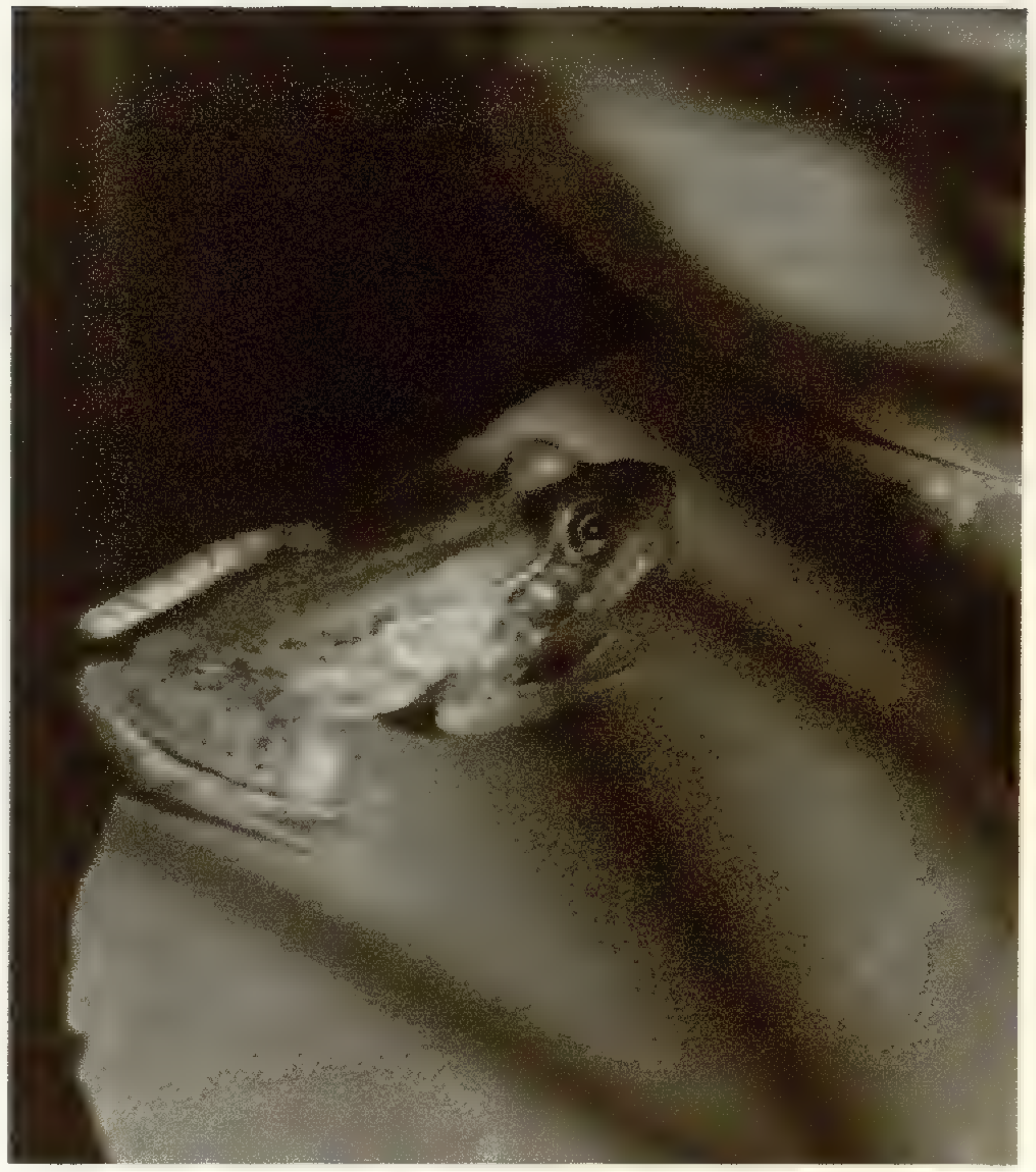


FIGURE 15

Photo of a green frog, *Rana clamitans*. Frog populations appear to be in decline over large regions of Canada due to habitat loss, pollution, and increases in ultraviolet radiation. The decrease in smaller and less well known species is difficult to document because of the lack of baseline studies, or because of natural annual variation. In other cases, such as lichens, museum records provide sufficient data to document significant declines in southern Ontario (*photo by Don McAllister*).

TABLE 4

SPECIES ENDEMISM IN SELECTED TAXONOMIC GROUPS

Taxonomic Group Species	Number of Native Species	Number of Endemic Species	% of Endemic	References
Vascular plants	3,269	45	1.4%	Argus and Pryer 1989
Freshwater molluscs	171	4	2.3%	Clarke 1981
Freshwater fishes	177	10	5.6%	McAllister 1990
Amphibians	40	0	0%	Cook 1984
Reptiles	41	0	0%	Cook 1984
Birds	426	0	0%	Godfrey 1986

The assumption that virtually all of Canada was glaciated has now been rejected. It is of historical interest that the discovery of clusters of Canadian endemics by biologists has preceded the acceptance by geologists (Warner *et al.* 1982) of certain glacial refugia. The discovery of new glacial refugia by geologists encourages the watch for more endemic species or unique races. Doubtless, more endemics will be discovered as taxonomic and geological knowledge advances.

Table 4 presents the numbers and proportions of known endemic species in six major taxonomic groups. One can deduce from the table that species which are sedentary or, like plants, rooted, can more readily develop endemic species or unique populations than ones that move about or migrate. The endemism in fishes results from geographical isolation provided by divides between hydrographic basins or by "refugial isolation" caused by glacial retreat.

While people often associate endemism with species, the concept also applies to lower levels (i.e. to unique genetic variants as exemplified by subspecies, varieties, physiological, and edaphic races). Thus, a unique population of a whale that is isolated from the main body of the species (as for example the Beluga of the St. Lawrence) can be said to be an endemic population. As well, a population harbouring unique genes (not found elsewhere in the species) can properly be said to be endemic to a certain area.

A particular application to Canadian biodiversity comes when we consider the possible uniqueness of plants in Canada that are found at the northern or southern limits of the range of the species, and therefore might be deserving of special consideration for protection. Special adaptive traits, genetically based but expressed physiologically, often characterize such populations (Mosquin 1966; 1971a; Scudder 1989). Such traits occur in species' populations across southern Canada, as for example in outlying prairie remnants of southern Ontario, in Carolinian forest fragments of southern

Ontario, in the many specialized dry areas across the southern prairies, and in the lower mainland valleys of British Columbia On this basis it can be expected that hundreds (thousands, if insects and other invertebrate species are included) of genetically and/or physiologically unique populations are found in Canada.

When such outlying populations are genetically adapted to Canadian conditions, these populations deserve protection. This is because it is not always possible to effect successful reintroductions by using individuals from more southern parts of the species' range. To demonstrate the presence of uniquely adapted "hardy" genetic races in such areas requires experimental work on a species-by-species basis.

Global warming would pose an ominous threat to the survival of marginal populations, because as the climate warms, such populations become subject to new stresses. Would they perish, evolve, or can they move? These issues are discussed by Parsons (1990), Hoffmann and Parsons (1991), Kareiva *et al.* (1993), and Gates (1993). These publications should be consulted for assessing conservation and resource management implications of maintaining biodiversity in times of climatic shifts.

Mitochondrial DNA evidence can now be used to study genetic differentiation in wild populations. For example, various Queen Charlotte Island morphologically distinctive local populations of the threespine stickleback, *Gasterosteus aculeatus*, probably had a common freshwater ancestor that inhabited periglacial (edge of the glacier) freshwater habitats, rather than each population being independently derived from marine forms (Gach and Reimchen 1989). At least one Queen Charlotte lake contains a pair of sympatric (living together in the same habitat) and distinctive populations, which behave like different species in that they do not interbreed although differing by less than 1% sequence divergence in restriction endonucleases. Similar conclusions can be drawn from earlier work by McPhail (1984) on sticklebacks on Texada Island and Enos Lake, British Columbia Two populations of rainbow smelt, *Osmerus mordax*, in Utopia Lake, New Brunswick, also do not interbreed and had sequence divergences of about 1.2% (Taylor, E.B. in litt.).

A special problem arises when discussing endemism at the provincial or territorial level in a country like Canada (Appendixes 4 and 5). For Canada as a whole, the amount of endemism would need to be based on the uniqueness of its biodiversity in comparison with other nations. Endemism in the provinces would be less pronounced, since a lower number of endemics would be present. Two areas, British Columbia and the Yukon Territory, are known to have more endemics because of their physiographic diversity and geological history. It is possible, with a thorough knowledge of the flora, fauna, and the location of specialized ecosystems in a province or territory (or any larger region of the planet), to draw some inferences as to where unique plants and animals are expected to be concentrated and therefore which areas should be considered on a priority basis for biodiversity conservation. In Canada, maps showing suspected or known concentrations of unique species (and other variants) have been prepared by the governments of British Columbia and Saskatchewan, and possibly by others.

5.2.3 ORGANISMS MODIFIED BY GENETIC ENGINEERING (OMGE)

Organisms modified by genetic engineering are self-reproducing organisms whose genetic makeup has been abnormally altered by the introduction of alien DNA or RNA from other species, or the translocation of DNA between or among the chromosomes of the same species, using the modern methods of genetic engineering. New genomes resulting from the traditional approach to the domestication of a plant or animal (i.e.

hybridization, selection) are not OMGEs. Neither are plant/animal varieties modified by cross-breeding with wild forebears or other closely related varieties or species classified as OMGEs. When a new OMGE is created, it adds to overall genetic biodiversity.

OMGEs that are created by transferring genes between closely related varieties or species might not be substantively different from those obtained by use of the traditional crossing methodology. However, what is new is that genetic engineering makes possible the transfer of genes or sets of genes from distantly related organisms that would otherwise never be able to exchange genes through cross fertilization. An OMGE can result when genes of a plant are introduced into an animal or vice versa, or into a bacterium from another distantly related bacterium. The transfer of genetic material may be carried out by an intermediate vector species, usually a micro-organism.

In Canada, considerable research into OMGEs is being carried out by Agriculture Canada. Environment Canada is developing guidelines. An elaborate system for testing and eventually using OMGEs has been established in several pieces of legislation.

Considerable concern has been expressed about the creation and release of OMGEs. Since the destiny of genetically engineered organisms cannot be second-guessed, it is not yet possible to say whether all of the concerns are realistic. We do, however, have six concerns:

1. given experience with exotic species and the availability of suitable habitat, there is a possibility, over time, that the OMGE will escape into the wild and impact negatively upon the normal functioning of some species in a natural system;
2. insofar as a OMGE was created from an exotic species, then the OMGE should be subjected to the same environmental impact analysis as introductions of an unmodified exotic;
3. the escape of OMGEs into the wild may result in genetic contamination of native stocks;
4. the environmental or human impact of the genetic modification, in combination with the original genome, should be examined. The transfer of a gene or set of genes endowing the new organism with a considerable relative or adaptive advantage might be considered a greater risk and subjected to careful analysis. Those crop OMGEs able to survive only under cultivation are obviously less of a risk than those capable of reproducing and spreading in the wild.
5. dynamic, naturally occurring evolutionary processes have an intrinsic, time-tested stability and can therefore be trusted to continue to be used in improving useful varieties. By contrast, the processes of genetic engineering and the fabrications they produce are alien, and carry attendant risks and consequences that are unpredictable and possibly untestable.
6. possibly the greatest risk is long-term, in that the creation of large numbers of useful OMGEs may further alienate humans from the normal, natural processes and functions of the planetary ecosphere. More people might simply accept the idea that nature's stable norms, including its wild species and ecosystems, can be dispensed with. The existence of such OMGEs may result in changes in attitudes where people come to accept or adopt technologies whose ecological sustainability are not testable and cannot be tested. To place one's trust in fallible, profit-motivated or politically motivated human judgment, rather than the stable workings of natural systems, would appear to place humanity's future at needless risk.

Depending on the species of organism into which new genes are transplanted, the

OMGE could be harmless, environmentally beneficial, a threat to human health, or a risk to the natural environment and humanity.

5.2.4. INTRODUCED SPECIES AND VARIETIES

Introductions of exotic species of both animals and plants have had varying impacts upon Canada's native species and ecosystems. In some cases, aliens have become extremely abundant, replacing native biotas to various degrees. Usually, their natural parasites or diseases are not introduced along with the exotic, giving the latter extra advantage. Numbers of species introduced in the different phyla vary from group to group. In some groups taxonomists cannot determine with certainty whether a species is introduced or not. For example, many bacteria, algae, insects, earthworms, centipedes, and others were almost certainly introduced, but direct evidence is lacking. As noted earlier, world travel and trade have turned the global spread of exotic species into a worldwide problem.

In Canada, among flowering plants, 884 species (some 30% of the native flora) are exotic (Scoggan 1978-79) and this number has since increased. Most of these introductions are weeds of disturbed places and farm fields. Examples of those known to have significant impacts upon natural systems (replacement

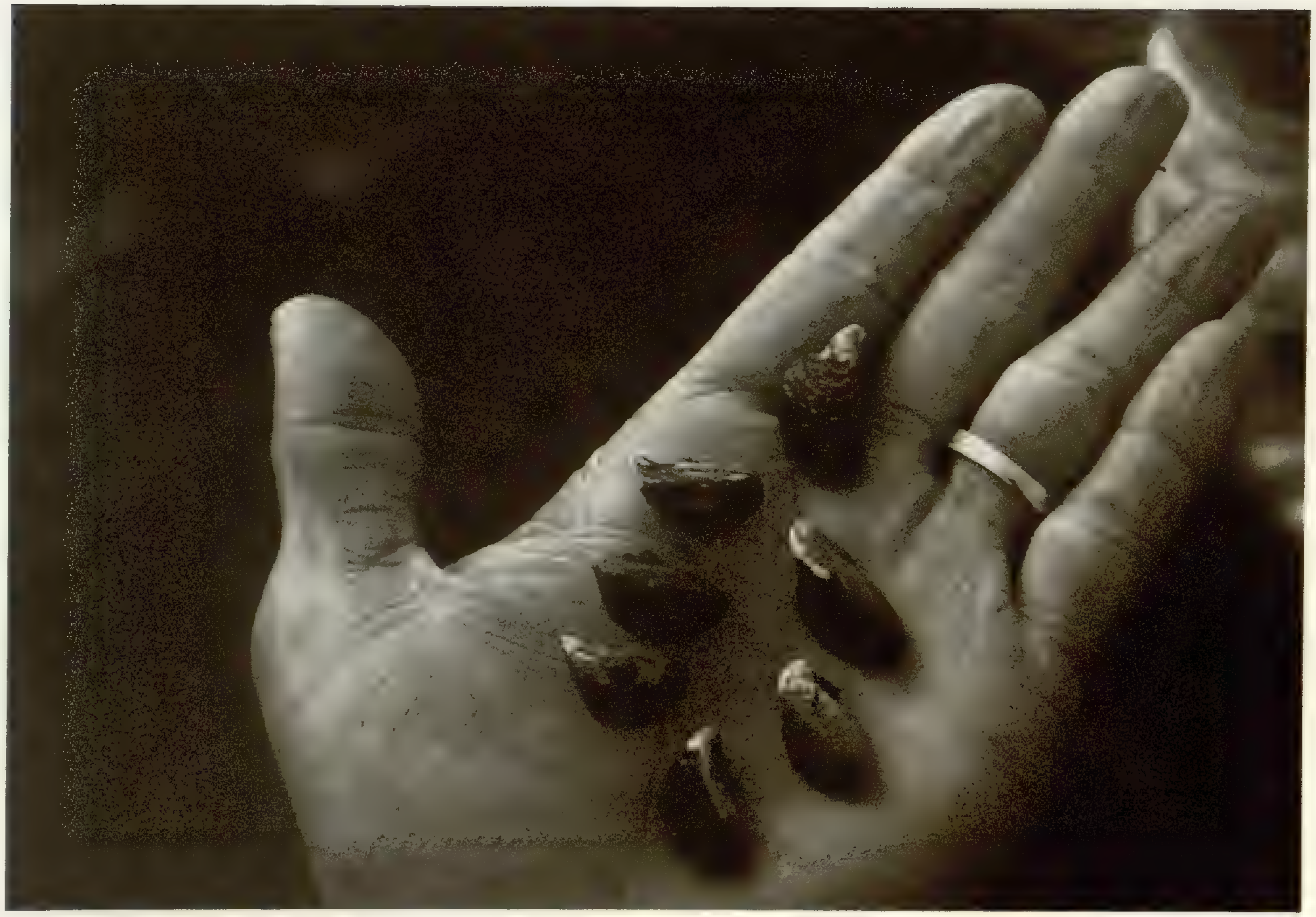


FIGURE 16

The zebra mussel, *Dreissena polymorpha*, is one of hundreds of species introduced to Canada and which displace native species from their habitat. Introduced into the Great Lakes basin in the 1980s, the zebra mussel now occupies large areas of underwater habitat, leaving little space for native mussels. Filter feeding by the mussel reduces the amount of plankton available for other invertebrate filter feeders and for larval fishes. The public and industry needs to become more aware of the potentially harmful effects of introducing exotic species (*photo by Dr. André Martel*).

of native species and major alterations of natural ecosystems) are listed in Table 5 where their principal effects are described. Many more species could be added to the Table.

The invasion of exotics around the world is continuing and probably accelerating, in view of world commerce and travel. Among fishes, 11 of the 1,102 species (1%) are exotic (McAllister 1990). Among the most recent destructive exotic species to be introduced into Canada are the zebra mussel and the European river ruff (Holloway 1992). The water ballast of ships is known to be the method of transport of many exotics. The economic costs of exotics (mainly exotic weeds in farm fields, pastures, and waterways) to Canadian agriculture and fisheries is high, when reductions in productivity and yield of desirable species, costs of applications of herbicides, tillage, and other actions are considered. It should be noted, however, that Canadian agriculture depends almost exclusively upon introduced exotic species for its crops. In some parts of the world the problem is so serious (and getting worse) that there is a growing fear of a biological 'homogenization of the world" (Culotta 1991).

There have been two kinds of fish introductions in Canada. The first involves the planting of hatchery stock into lakes or rivers normally containing that species. Such

TABLE 5

LIST OF INTRODUCED, NON-DOMESTICATED SPECIES THAT HAVE HAD A MAJOR IMPACT ON THE STRUCTURE AND FUNCTIONING OF CANADA'S NATURAL ECOSYSTEMS

Name of Species	**Year Introduced**	**Nature of Major Effect Upon other Species and/or the Ecosystem**
FUNGI		
Dutch Elm Disease *(ceratostomella ulmi)*	1944 at Saint-Ours, Quebec (from Europe via USA)	Caused an enormous loss of the American Elm (*Ulmus americana*), especially in forests and swamps. Isolated Elm survive in open farm country. Fungus is transmitted by elm bark beetles of genera *Scolytes* and *Hylurgopinus*.
Chestnut Blight	ca. 1900 from Asia (China)	Virtually extirpated the American Chestnut, *Castanea denatata*, as a seed-reproducing tree in all of its range.
PLANTS		
Frog-bit *(Hydrocharis morus-ranae)*	1939	Shades out submergent vegetation by forming dense mats at the surface (marshes) (Catling *et al.* 1988).
Scotch broom *(Cytisus scoparius)*	1800s ?	Replaces native flora; major competitor for moisture in dry sites of southwest B.C.
Swamp Loosestrife *(Lythrum salicaria)*	early 1900s ?	Aggressively replaces many marsh, swamp and wet meadow species; forms pure stands.
Downy Chess *(Bromus tectorum)*	1600s ?	Aggressively replaces native grasses & forbs in dry regions of the prairies and southern B.C. Introduced by the Spanish into Mexico and then spread northward.
Crested Wheat Grass *(Agropyron cristatum)*	deliberate introduction by governments; year not known	Aggressively competes with native species in southern prairie provinces. Major problem in Grasslands National Park (Romo and Lawrence 1990).

Grass *(Agropyron desertorum)*	?	This Asian grass replaces native species in native grasslands; planted by ranchers.
Grass (*Elymus junceus)*	?	This Asian grass replaces native species in native grasslands; planted by ranchers.
Smooth Brome *(Bromus inermis)*	between 1875 and 1888 (Romo and Grilz 1990)	Suppresses & displaces native species in native prairie grasslands in western Canada; persists in roadsides and open areas across Canada thereby preventing the colonization of these areas by native species.
European Birch *(Betula sp.)*	?	Cultivar; invades natural bog ecosystems.
European Water milfoil *(Myriophyllum spicatum)*	late 19th century (Aiken *et al.* 1979)	Creates dense submergent growth in eutrophic waters at expense of many native submergents.
FISHES		
Carp *(Cyprinus carpio)*	1880	Muddies up marshes; destroys submergent vegetation, food and cover.
Sea Lamprey *(Petromyzon marinus)*	1921	Parasite; killed large numbers of fishes following entry to upper Great Lakes through Welland Canal.
BIRDS		
Common Starling *(Sturnus vulgaris)*	1890	Usurps nesting cavities for bluebirds, woodpeckers, swallows, etc.
House Sparrow *(Passer domesticus)*	1850	Usurps nesting cavities for bluebirds, woodpeckers, swallows, chickadees, etc.
MAMMALS		
Norway Rat *(Rattus norvegicus)*	1775	Naturalized on bird islands and shorelines of Atlantic & Pacific (e.g. Q.C.I.); destroys nests & eggs of colonial seabirds.

hatchery stock may undergo selection while under human care. Or, the stock of origin may have come from different ecological conditions from that native to the body of water into which the stock is planted. Introduction of alien stock into a lake with native stock often results in genetic contamination. Insofar as the contamination is maladaptive to local conditions, temperature, inlet/outlet lake spawning, and so forth, there are often negative impacts to the planting.

A second kind of introduction is when a species not native to a drainage basin or country (exotic introduction) is planted into a water body. Such introductions can displace local species. For example, brown trout, *Salmo trutta*, introduced in insular Newfoundland (Scott and Crossman 1964) are displacing native brook char (*Salvelinus fontinalis*). In other cases, exotic species may disturb habitat for native species, as is well-known for carp, *Cyprinus carpio*, introduced into the United States and Canada. In yet other cases, the introduction of related species or subspecies may result in hybridization and genetic degradation of the native species or even its extirpation or extinction. Native cutthroat trout, *Oncorhynchus clarki*, in Alberta have hybridized with rainbow trout, *Oncorhynchus mykiss*, introduced into Alberta streams (Nelson and Paetz 1992). The Banff longnose dace, *Rhinichthys cataractae smithi*, endemic to Cave and Basin Hotsprings in Banff National Park, was extirpated in part due to competition/predation from the introduction of exotic aquarium fishes, and in part from hybridization with *R. c. cataractae*. Some fish species introduced into U.S. waters have spread into Canadian waters through shared water basins in Ontario and British Columbia.

5.2.5 DOMESTICATED SPECIES

By far the greatest impact upon Canadian biodiversity stems from the wholesale conversion of natural systems for agriculture, ranching, and urban development. In ranching, severe overgrazing, or the planting of exotic grasses (Table 5) and forbs also causes significant damage to normal biodiversity, especially where dominant native prairie species are replaced.

Farmland in 1986 occupied 678,000 km^2 or 6.7% of the Canadian total land mass. This amounts to a large percentage of the southern and most biologically diverse half of Canada. The greatest ecosystem conversions have taken place in southwestern Ontario, the southern prairies and the lowland valleys of southern British Columbia. In these regions, conversions may reach over 90% of the landscape with the balance being

TABLE 5 (CONTINUED)

Name of Species	Year Introduced	Nature of Major Effect Upon other Species and/or the Ecosystem
Horse *(Equus caballus)*	1600s	Sable Island, N.S. Major destruction of native vegetation cover, accelerating wind erosion of sand dunes, impacting on many species, e.g. the Ipswich Sparrow.
Mule Deer *(Odocoileus hemionus)*	1900/1916	Queen Charlotte Islands; overgrazes forest ecosystems & selectively impairs regeneration of shrubs and key tree species.
Raccoon *(Procyon lotor)*	1940s	Queen Charlotte Islands; competes aggressively for food in intertidal zone; raids seabird colonies.
INVERTEBRATES		
Gypsy moth *(Lymantria dispar)*	1868 (Mass.) years.	Defoliates large tracts of forests in peak.
Golden Nematode potato crops in Vancouver	? Island and	Herbivore pest in many plants; decimated.
Newfoundland.		
Zebra mussel *(Dreissena polymorpha)*	1980s	Southern Ontario waterways; occupies large areas of underwater habitat & displaces native species of clams; its filter-feeding "efficiency" reduces the amount of plankton available to native filter feeders and larval fishes; significantly affects light penetration and abundance of submergents in lakes and rivers.

fragmented and degraded to various degrees. Conversions involve grasslands, forests and wetlands. Wetland habitat for wildfowl in southern Ontario and the Prairie provinces has been reduced by 68% and 71% respectively, largely because of agricultural uses and drainage (Environment Canada 1991b) In these agricultural areas only small remnants of original ecosystems remain, and no doubt the ecological functions of these fragments are weakened or lost.

Impacts of domesticated species are not restricted to the lands that are farmed. An indirect effect of domestication of plants and animals is that farms usually export sediments, nutrients, and pesticides into aquatic and even marine ecosystems. The farms, orchards, and ranches on these converted lands form the essential basis for much of Canada's agricultural economy. Appendix 11 lists the major exotic animal and plant species, now being raised or growing on these lands.

The most commonly raised animals are cattle, sheep, horses, and less often, pigs, chickens, geese and turkeys, although these hardly ever range freely today. Principal Canadian crops are the cereal grains: wheat, corn, barley, and oats. Oil seed crops can sometimes provide high net returns to the farmer. In particular, soybean, sunflowers and canola are extensively planted. In orchards, apples, peaches, grapes, pears, and cherries predominate. While the great majority of agricultural crop plants are exotics, some native species are now actively cultivated for food for people. The best known of these are the Saskatoon Berry *(Amelanchier alnifolia)*, Bog Cranberry *(Vaccinium macrocarpon)*, Wild Blueberry *(Vaccinium angustifolium* and *V. myrtilloides)*, and Wild Rice *(Zizania aquatica)*.

Canada's farms and ranches are thus in the business of conserving a range of exotic and native varieties of a wide number of species of animals and plants containing genetic characteristics that optimize their productive value to people and support the economy of the nation. Certainly, humans have created new gene combinations in both crops and domesticated animals. However, unlike the native species, it is almost certain that all these useful variants would soon vanish completely were it not for active tending and conservation of their genetic material by various institutions and private groups (Appendix 10).

Domesticated species carry out several ecological functions in a manner similar to wild species, but an examination of Table 2 reveals that while some functions are retained, large numbers are lost from the system. However, again the almost sole beneficiaries of the presence of these species are humanity's domestic animals and people themselves, and these benefits are provided at the expense of previously existing biodiversity. It has been estimated by Vida (1978) that modern agriculture reduces genetic diversity by three orders of magnitude at least. This would mean that when agriculture replaces a natural system, some 1,000 genes are lost for each new one that is gained.

The impacts of domesticated cattle, horses, sheep, and other species upon the ecological health of riparian habitats and those of streams, rivers, and lakes is often severe, due mainly to continuing eutrophication of waters, erosion, siltation, and the depletion and degradation of soils. These trends are largely documented in the State of the Environment Report (Environment Canada 1991c). For most parts of Canada, such impacts upon natural systems are not discouraged by government policy and legislation. For example, provincial subsidy programs have facilitated the drainage of wetlands and channelization of streams.

Pitt and Hooper (1994) have described the damage livestock cause to grassland microphytes—the organic crusts of lichens, mosses, and cyanobacteria. These crusts, well-developed in arid grasslands, enhance soil moisture retention and soil nitrogen levels, but are readily damaged by livestock trampling.

TABLE 6

DOMESTICATED SPECIES AFFECTING ECOSYSTEM DIVERSITY

Species	Introduction Date	Effect on Biodiversity
House cat	1700s	• reduce native bird populations
Dogs	1700s	• predation on deer
Honeybees	1700s	• compete with native bee pollinators for nectar and pollen of native plants • pollinate native plant species
Livestock	1606—cattle (Acadia) 1610—cattle (New France)	• affect water quality in streams and ponds • reduce diversity of native plant species, grassland microphytes, and dependent organisms in forests, natural ponds prairie, etc. • cause stream bank erosion and associated changes to shoreline flora and fauna • cause eutrophication of streams and increases in "waterweeds" • introduce disease to wild animals such as bison (see text)
Crops		• conversion of native ecosystems into monocultures (see text) and fostered introduction of exotic weeds • fertilizers and pesticides toxify soils, streams, affecting native plants, and animal habitat • affect hydrological cycles and, through sedimentation, the aquatic habitat
Orchards, horticulture		• fertilizers and pesticides toxify soils, streams, affecting native plants and animal habitat • conversion of natural ecosystems into monocultures and areas with exotic weeds

Game ranching using native or introduced species such as elk, deer, bison, and other species is increasing and beginning to pose a threat to both native species and to ecosystems. Ranching of exotic species carries the threat of hybridization with native species and the introduction of parasites and diseases. For example, in the past several years two tuberculosis epidemics in western Canada have cost the taxpayer about $20 million. As well, a new exotic disease has been imported from New Zealand. In about 1980, bighorn sheep in southern Alberta were decimated by a disease of domestic sheep and have still not recovered. The legal sale of ranched wildlife meat increases the opportunities for the illegal sale of meat from native species. Game ranching can be less harmful to the integrity of natural systems than cattle or sheep ranching. However, high stocking densities and artificial management of range displace many native species and cause overgrazing that essentially reduces natural ecosystems to the equivalent of cattle pastures. Some additional impacts of Canada's introduced domesticated species are presented in Table 6.

5.3 HABITAT/ECOSYSTEM DIVERSITY

Appendix 3 summarizes the principal sectoral ecosystems of Canada, estimates total area of each, and describes some of the more obvious functions or roles played by organisms and ecosystems in each.

5.3.1 PATTERNS IN NUMBERS OF SPECIES WITHIN ECOSYSTEMS

The diversity of habitats/ecosystems in Canada is shaped strongly by two dominant patterns in the geographical occurrence of species. The first is geographic trends or clines; the second is the occurrence of hotspots. Hotspots are geographic areas relatively rich in species and higher taxa such as genera and families, or in endemic species, subspecies, or unique populations.

Clines: Clines in numbers of species may be geographic, altitudinal, or bathymetric. In many taxa the number of species increases toward the equator. This is generally true for species of land animals and vascular plants. For example, in the Queen Elizabeth Islands, the northernmost half of Canada's Arctic Archipelago, there are less than a dozen native species of land mammals, which include the caribou, polar bear, wolf, Arctic fox, Arctic hare, and lemmings. The Yukon has 64 species (including marine) (Youngman 1975). In British Columbia, we find 126 species (Cowan and Guiguet 1965). Similarly amongst Canada's marine fishes there are 111 Arctic species, whilst on the southern coasts there are 371 Pacific species and 527 Atlantic species (McAllister 1990). However, equatorial trends in marine species are less well documented (Clarke 1992). Similarly, altitudinal clines are found with fewer or no species at the tops of the higher peaks and many toward mountain bases. Most Canadian lakes have more species in the shallow than the deeper waters. A similar cline was thought to exist from shallow coastal to deep ocean depths. Rex (1983) studied clines in polychaetes, gastropods, protobranchs and cumaceans along a depth gradient from shallow water to 5,000 m. He reported a maximum diversity between 2000-3000 m.

Hotspots: Hotspots are located by mapping the number of species per unit area for the globe or some area of it. Hotspots can be determined for species of taxonomic groups such as birds, fishes, or for a genus such as the goldenrod, *Solidago*, whose hotspot or centre of distribution is located in eastern North America. Hotspot occurrences can also be determined for species selected on a special basis—tree-like plants or endemic species—those restricted to a relatively small area. Knowledge of clines and hotspots is important for conservation, and for identifying areas showing promise in the search for pharmaceuticals or for other applied uses.

FIGURE 17

Marine Kelp on a sand beach. Canada's west coast is a planetary hotspot in marine seaweeds.

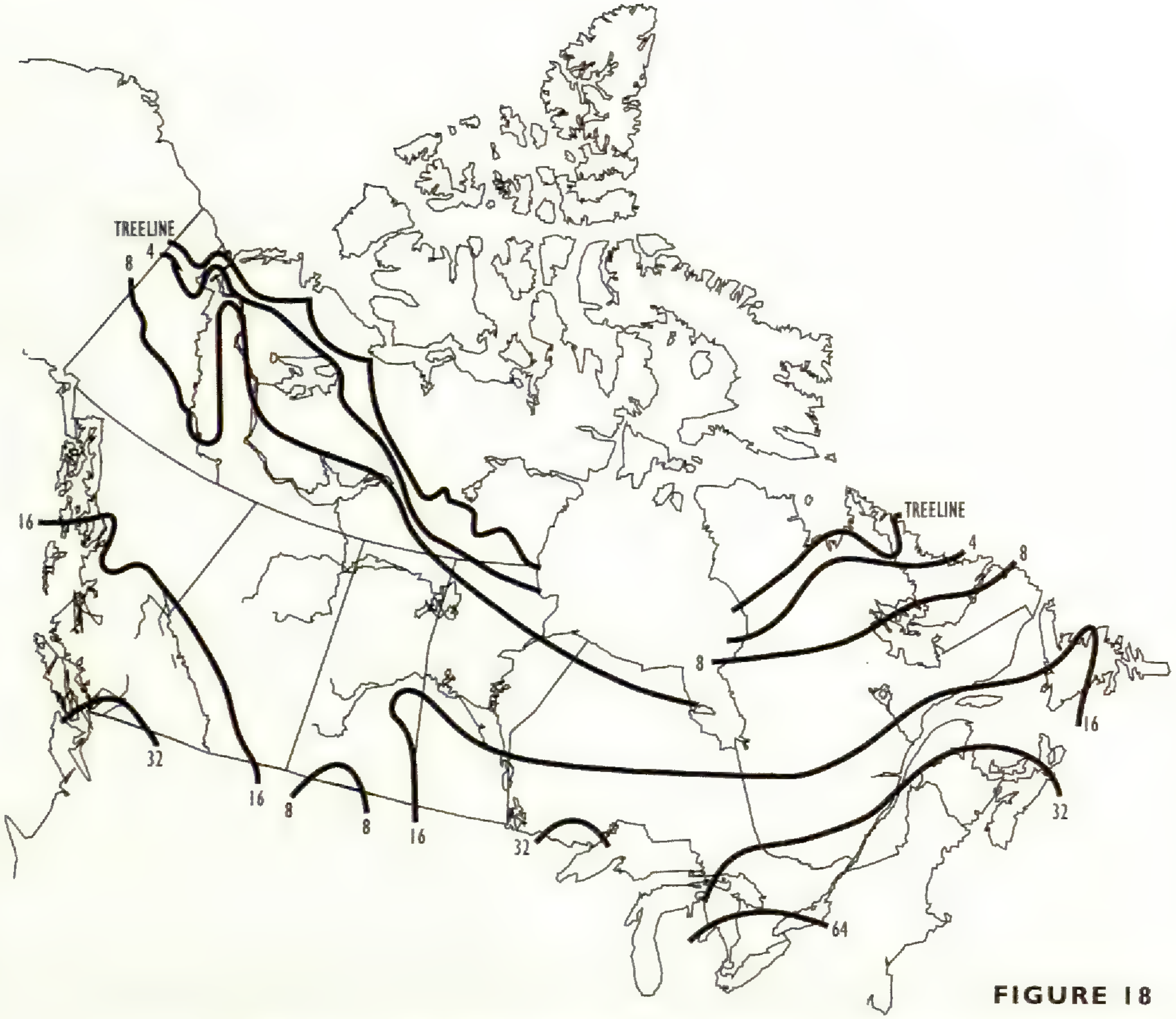


FIGURE 18

Hotspots for tree biodiversity in Canada. Biodiversity is not evenly distributed across Canada. As can be seen from this figure, the number of tree species is highest in southern Ontario and in southern British Columbia. By assembling distributional data from scientific collections in museums and herbaria, one can locate hotspots with concentrations of species in different taxonomic groups. These hotspots should have high priority for biodiversity conservation and for ecological and biotechnological studies. The hotspots for different groups of animals and plants often do not coincide, so the occurrence and distribution of all taxa require study to better ensure maximum protection for biodiversity (*map from Fred Schueler and Don McAllister 1991, courtesy of* Global biodiversity).

An important observation on hotspots is that their locations may not coincide for different taxonomic groups. Anderson's studies (1984a; 1984b) showed that the North American hotspot for birds was northwestern Mexico and southwestern U.S., while McAllister *et al*. (1986) showed that the principal hotspot for freshwater fishes was in the Cumberland-Tennessee Plateau between the Mississippi River and the Appalachians. This would mean that different parks/reserves may have to be established to protect different taxonomic groups as was proposed in 1988 for large Canadian carnivores by Bath, Dueck and Herrero as summarized in Hummel and Pettigrew (1991, 176-181). Thus, higher taxonomic groups as well as species numbers should be taken into account in hotspot analyses (McAllister 1993d and 1994).

5.3.2 FORESTS

Today, about 45% of Canada, or 4,530,000 km^2, is covered by forests. This represents about 10% of the planet's forests. The original forest prior to European colonization was 5,300,000 km^2. Hence, 770,000 km^2 has been permanently deforested. Of today's forested lands, about 2,330,000 km^2 are suitable for commercial timber extraction using today's technology.

Canada's natural forests are a varied mosaic of changing communities and include a great variety of ecosystems. Rowe (1972) recognized 8 major forest regions divided into 90 geographical sections. At the extremes we find Carolinian hardwood forests in southern Ontario, sparse spruce boreal forests in the north, and temperate rainforests along the B.C. coast with massive thousand-year-old red cedars. The ecological values of Canadian forest ecosystems are manifold:

1. they provide for species uniquely adapted to the realm of the tree. Across the breadth of Canada, the geographical extant of forests makes possible a great variety of animal, and shade-requiring plant species dependent upon the existence of forest and on the unique microclimate maintained by the trees and shrubs. There are literally thousands of species of biota from tiny invertebrates up to large herbivores that depend upon trees and shrubs or forest litter and soils, including canopy nesting birds and cavity requiring mammals and birds. Many Canadian carnivores need forest for food, cover, and living space.
2. forests function heavily in watershed protection and runoff moderation, particularly in more mountainous regions;
3. due to transpiration and the cooling effect of the canopy, forested lands play significant roles in moderating regional and global climate;
4. the enormous biomass of roots, dead leaves, trunks, and branches provides the essential ingredients for the formation of soils and for rich assemblages of soil invertebrates and micro-organisms, mostly unseen and unsensed. When added to lakes and streams, stem, bark, and leaf detritus provides indispensable food for many stream biota;
5. trees store large amounts of carbon in their living and dead leaves, twigs, branches, roots, and trunks (Section 4.7). Large woody fragments in the soil and living wood reduce the level of CO_2 in the atmosphere.

Effects of management upon forest biodiversity and ecological functions in Canada have been reviewed by Boyle (1991), Hammond (1991), McAllister (1993e), and others. Today, clearcutting in extensive old growth boreal regions of Alberta, Saskatchewan, Manitoba, Ontario and some other provinces, and also in the remaining old growth forests of interior and coastal British Columbia is actively pursued by industry and provincial governments. With each passing year, Canada has a shrinking supply of "old growth" or normal forests. Logging is being expanded into areas

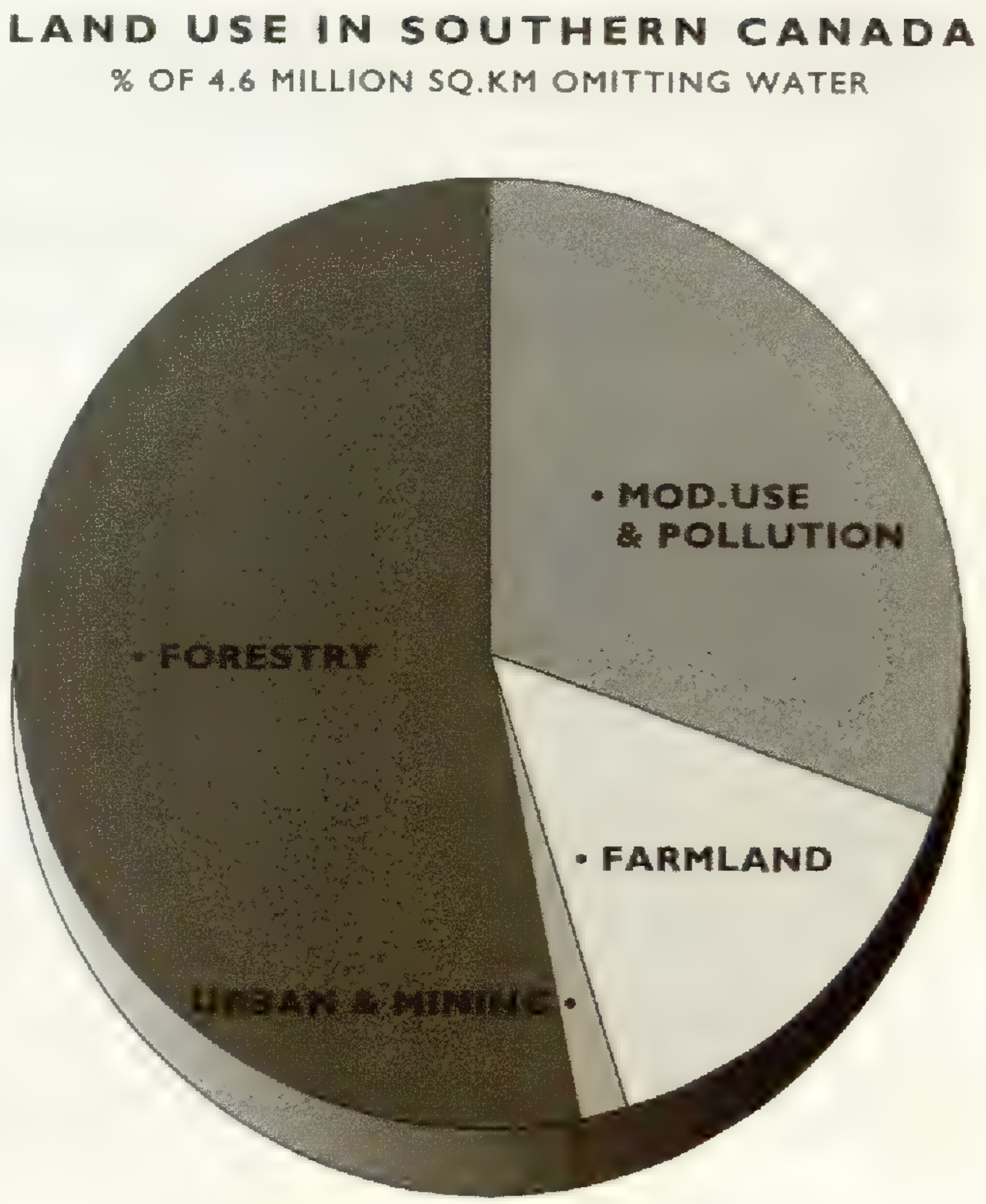
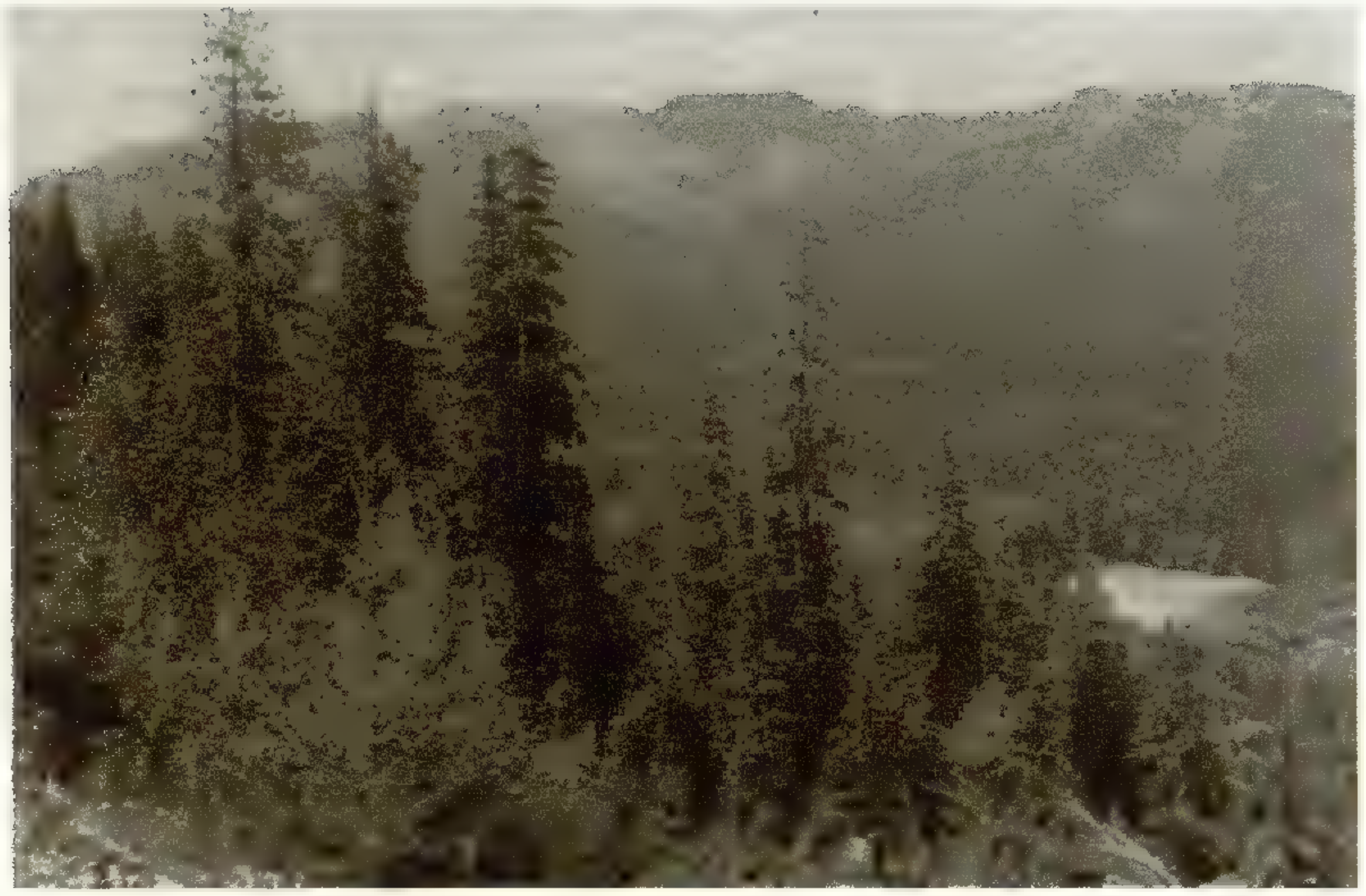


FIGURE 19

Graph showing percentage of the southern half of Canada affected by various land uses. The forest area is based on stocked productive forest land (*graph by Don McAllister*).

never logged before including ever more marginal regions, affecting both present and future biodiversity.

Plantations can be found in the more settled areas of southern Canada (Figure 20), and especially on lands marginal for agriculture. Plantations to date comprise only a tiny part of forested regions, but the proportion is growing. Tree plantations tend to be monocultures. In many provinces the practice of planting single or low numbers of species over large holdings of recently logged public forest lands, coupled with spraying for commercially undesirable species is widespread. This practice is causing structural and compositional changes to local biodiversity, contributing to atmospheric dispersal of these toxins to distant lands and waters, adding to stream pollution, and affecting various animal and plant species. In some provinces (Ontario, for example) spraying is regulated with the aim of preventing harm to fish populations and reducing risks of contamination of water for human consumption. The scale of forest clearcuts upon the landscape in many parts of Canada can be seen from airline flights across Canada. Clearcuts near Bowren Lake, British Columbia, are visible from satellites.



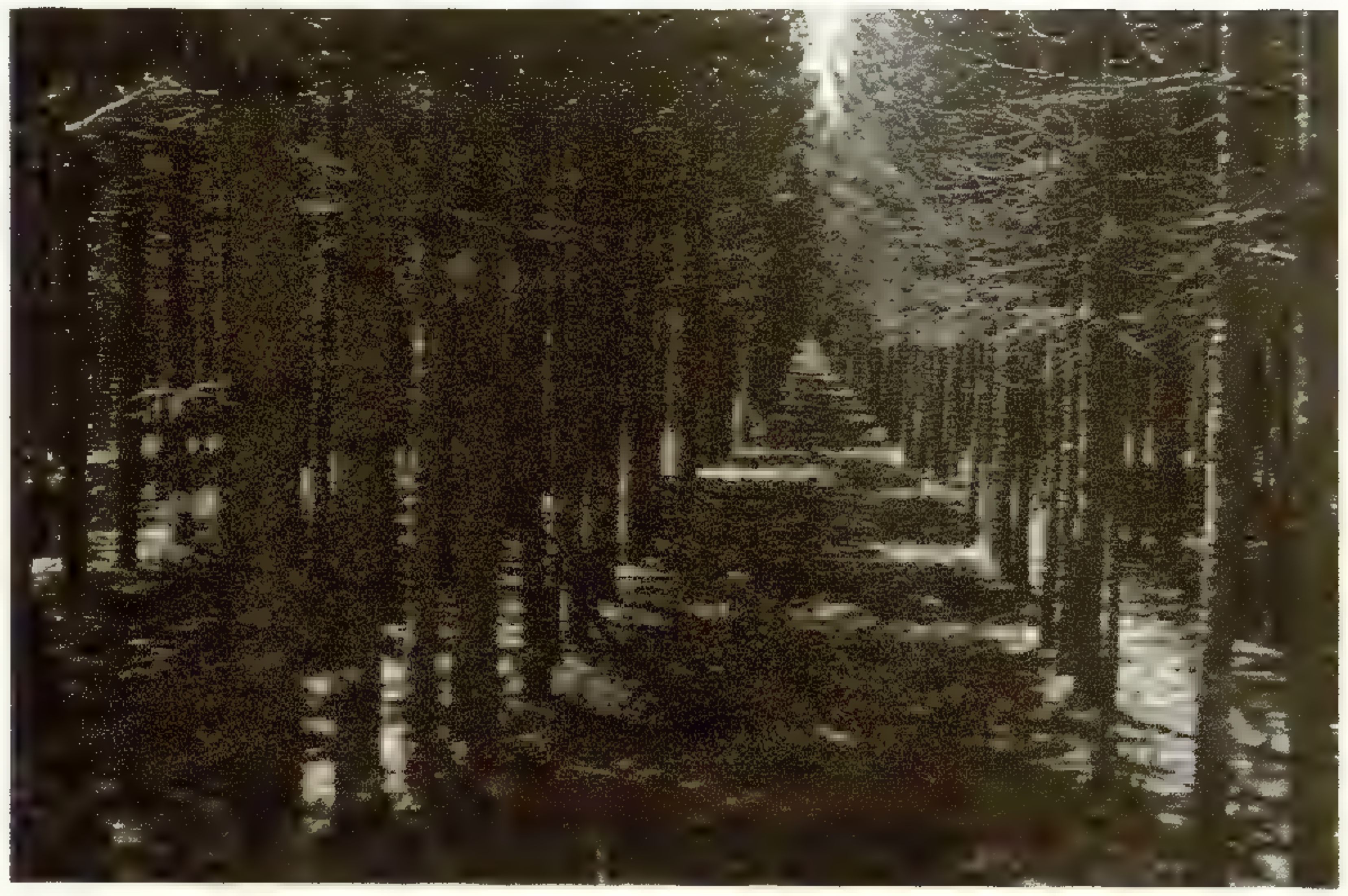


FIGURE 20

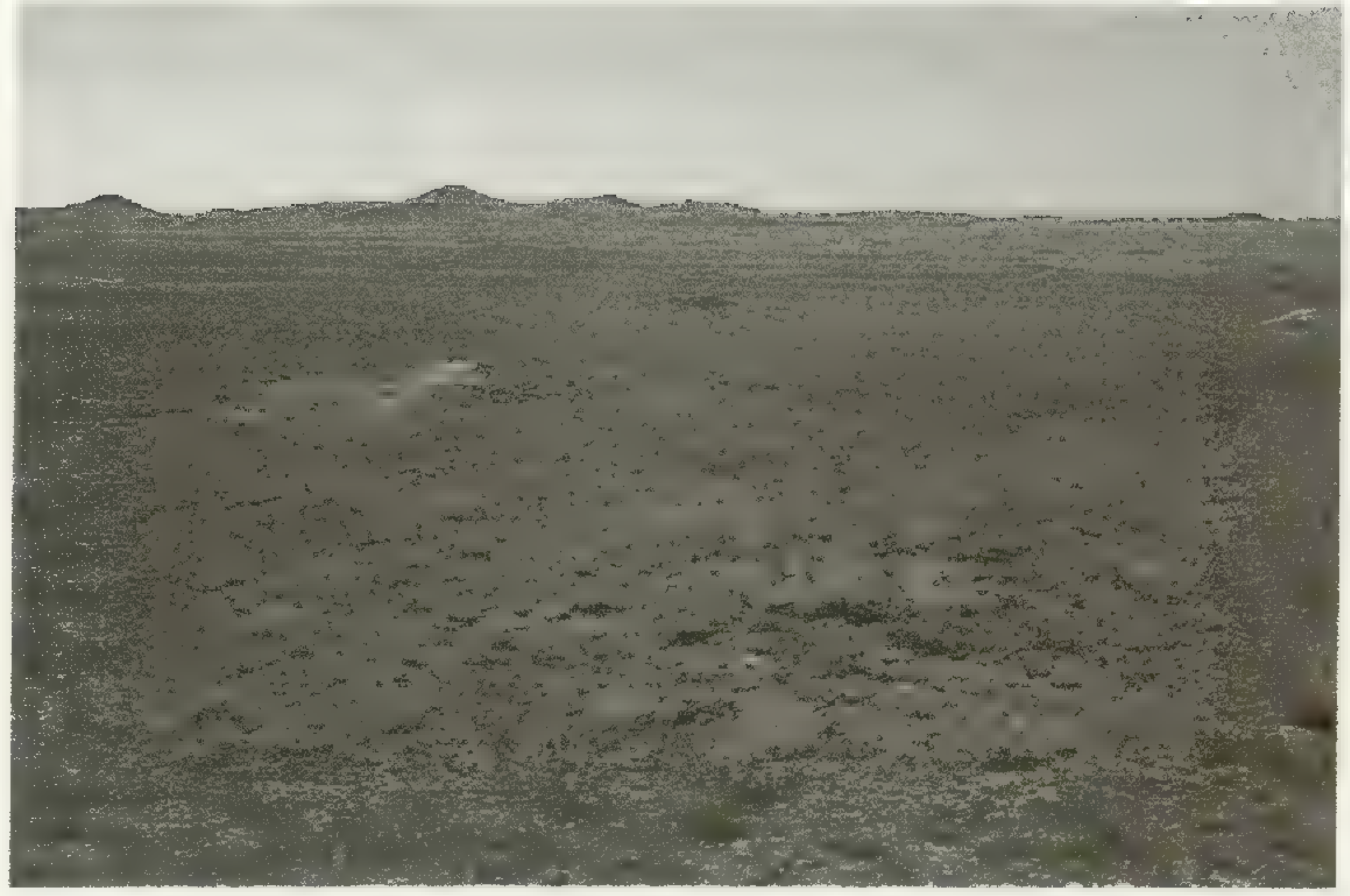
ABOVE: This scene shows one of the types of forests that covers 45% of Canada's land area, and represents 10% of the world's forests. The value of spruce trees alone represents about $4 billion, many jobs in the forest and in secondary industry. At the same time, those trees create oxygen, bank carbon, and provide structural habitat for many wildlife species and countless micro-organisms (*photo by Don McAllister*) BELOW: Forest plantations such as this drastically reduce biodiversity. This method of forest regeneration is not compatible with enlightened biodiversity conservation. Monoculture plantations further encourage the multiplication of pests and unbalanced soil nutrient use (*photo by Ted Mosquin*).

5.3.3 GRASSLANDS

In 1750 the natural grasslands of Canada occupied about 500,000 km^2. Canada's original grassland ecosystems have been categorized as short grass prairie and tall grass prairie, with the former located in the drier parts of Alberta, Saskatchewan, and Manitoba, and the latter originally occupying parts of south-eastern Manitoba and small areas of south-western Ontario.

About 60% of Canada's grasslands are now under cultivation (Environment Canada 1991c). About 10% of land in British Columbia is grazed by domestic stock (Pitt and Hooper 1994). Today, fragments of the original grasslands can be found on coulee banks, old railway rights of way, in protected areas such as parks, and in ranchlands that have not been seriously overgrazed or converted (with exotic grasses and forbs) into managed pasture. Estimates of remaining grassland ecosystems have been made by the World Wildlife Fund (1989).

Natural grasslands have deep rich soils whose origins can be traced to the extensive root systems of prairie grasses (Weaver 1954), recycling of roots, stems, and leaves, and the droppings of animals such as bison, antelope, gophers, and other prairie animals. The large agricultural economy of western Canada is firmly rooted in the soil fertility



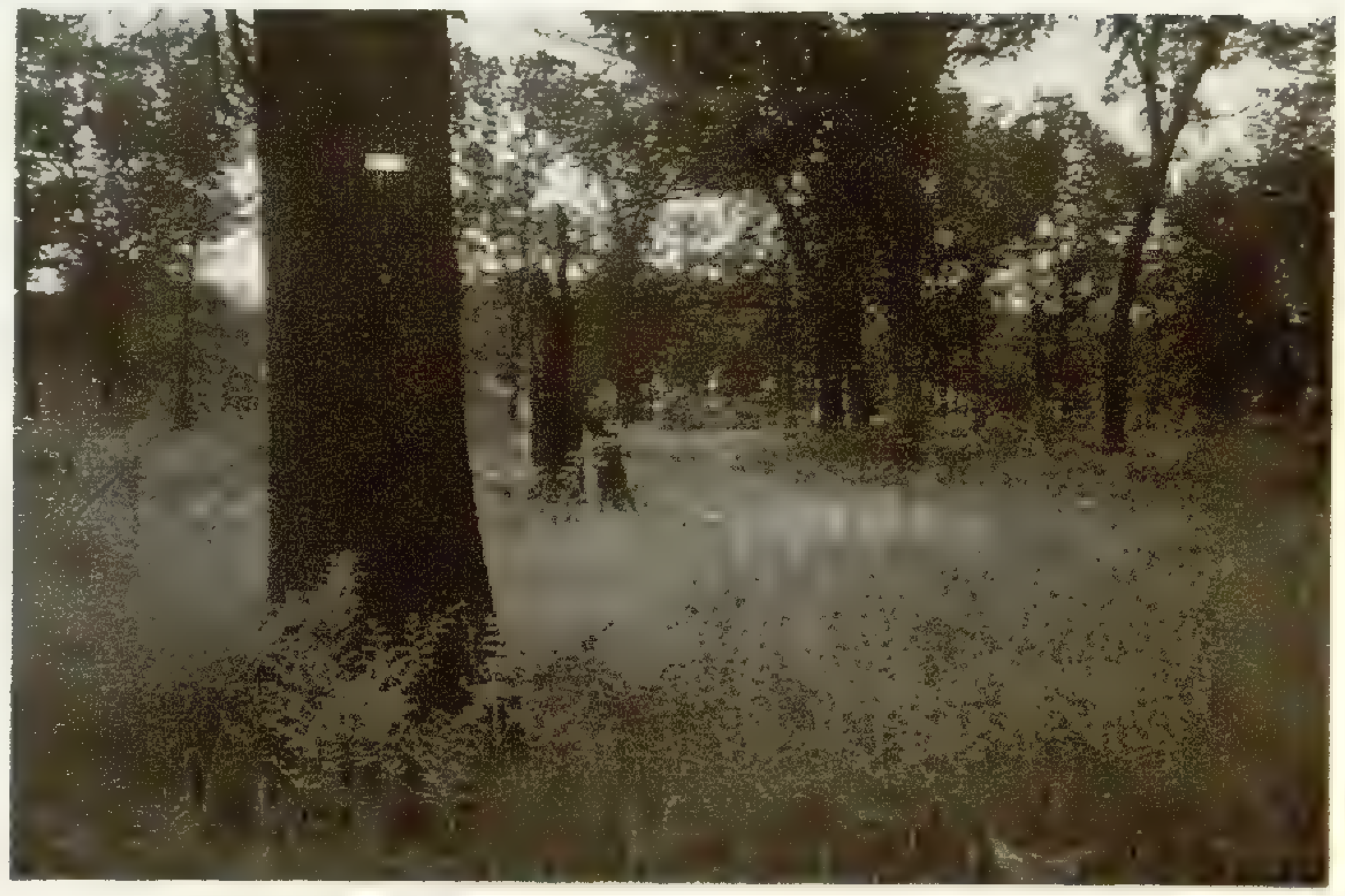


FIGURE 21

ABOVE: Short-grass prairie in southern Saskatchewan, showing mounds of soil at entrances to burrows of the Black-tailed Prairie Dog, *Cynomys ludovicianus*, a vulnerable Canadian species. These burrows are sometimes used as a nest site by the Burrowing Owl, *Athene cunicularia*, a threatened species. This site was secured by the Saskatchewan Natural History Society, and was the first private nature sanctuary in Saskatchewan (it is now part of Grasslands National Park). BELOW: Tall-grass prairie remnant on Walpole Island Indian Reserve on the delta of the Detroit River, southern Ontario. Canada's native grasslands are amongst the most degraded or lost in Canada. About 99% of Canada's tall-grass prairies have been converted to farmland *(photos by Ted Mosquin)*.

and productivity of converted prairie ecosystems as are some of the farmlands of southern Ontario, especially just east of Lake St. Clair and along the north shore of Lake Erie, which harboured grasslands at the time of colonization by Europeans.

However, soil quality in converted grasslands has declined. Some 40% to 50% of the original soil organic matter has been lost on the Prairies and 30% to 40% in central and eastern Canada (Environment Canada 1991c). Loss of soil quality has been accompanied by soil erosion, compaction, and in some areas, soil acidification and dry land salination. As well, there has been a five- to ten-fold increase in levels of application of fertilizers and pesticides on large areas of the Prairies. While grassland soil biodiversity has not been monitored, there are indications of impacts. Thus, the conversion of grasslands to cultivated cropland is known to disrupt insect and mite species diversity to such an extent that the soil found would take over 25 years to recover (Environment Canada 1991c).

Parks Canada is considering the active restoration of a significant area of short grass prairie within the bounds of the newly established Grasslands National Park (Romo and Lawrence 1990), while a small area of tall grass prairie is currently being restored in eastern Manitoba by the Manitoba Naturalists Society.

5.3.4 WETLANDS

There are literally hundreds of thousands of wetlands in Canada and these range in size from a fraction of a hectare to more or less continuous bog and fen wetlands stretching across enormous parts of the boreal forest, particularly in the James and Hudson Bay lowlands of northern Ontario.

Almost one quarter of the world's wetlands occur in Canada. Wetlands are found along lakes, streams, coastlines, and as isolated pockets across the breadth of the country. They include salt marsh estuaries along all marine coastlines, inland marshes, fens, bogs, and swamps. In southern Alberta, Saskatchewan, and Manitoba, many wetlands are isolated "potholes", and in the most arid areas, the pothole wetlands are saline. In areas of temperate rainforest, as for example in the Queen Charlotte Islands, extensive treed bogs may develop on hillsides. String bogs are abundant in northern Canada and possess characteristic alternating strips of trees and herbs, often perpendicular to the surface flow.

About 12% of Canada is said to be wetland (World Wildlife Fund 1991)—the bulk of this being bog and fen in the boreal forest.

The main biodiversity function/value of wetlands lies in their being unique habitats where land and water come together. This means that terrestrial animals require them for parts of the year and that many of the animals living in wetlands are dependent for a part of their lives on adjacent uplands.

Wetland ecosystems, especially bogs and fens, often accumulate large deposits of organic soils. They are sinks for nutrients and have a significant water quality improvement function (Ontario Ministry of Natural Resources 1984). Wetland ecosystems are the required breeding or feeding grounds for thousands of species at the base of food chains, including a wide range of invertebrates that feed mammals and dozens of migratory bird species. In many parts of southern Canada, extensive wetlands have been drained and converted to other uses, mainly agriculture. Purple loosestrife, an exotic species, has displaced a considerable proportion of native species in Ontario wetlands. At the same time, economically marginal agricultural lands have been abandoned over many decades, and wetland restoration is a goal of some government agencies and non-government groups such as Ducks Unlimited. Some methodologies for restoration are discussed in Kusler and Kentula (1990).

5.3.5 FRESHWATER RIVERS, LAKES AND AQUIFERS

Canada's rivers and freshwater lakes make up at least 7.6% of the country's land mass, an area totalling 755,000 km^2. They have an effect upon local and regional climate through their function as year-round heat sinks and because of evaporation during summer months. Large rivers such as the MacKenzie transport warmer water across climate boundaries and influence local ecosystems, others convey cooler water from mountains to the plains.

The ecological and economic effects of river and lake ecosystems derive principally from geographical location, latitude, altitude, water volume, and water quality. The Great Lakes have special significance due to their size. Some species such as lake char and introduced Pacific salmon *(Oncorhynchus)* can be found in great abundance because of the presence of deep, cool waters in the summer. Alpine and arctic lakes and rivers are relatively cold throughout the summer and are ice covered for long periods. Ecosystems of most southern lakes and rivers are variously eutrophic due to often severe enrichment from cottages, nearby houses, sewage plants, municipal dumps, and agricultural runoff. Across southern Canada, freshwater systems are often intensely turbid due to plankton

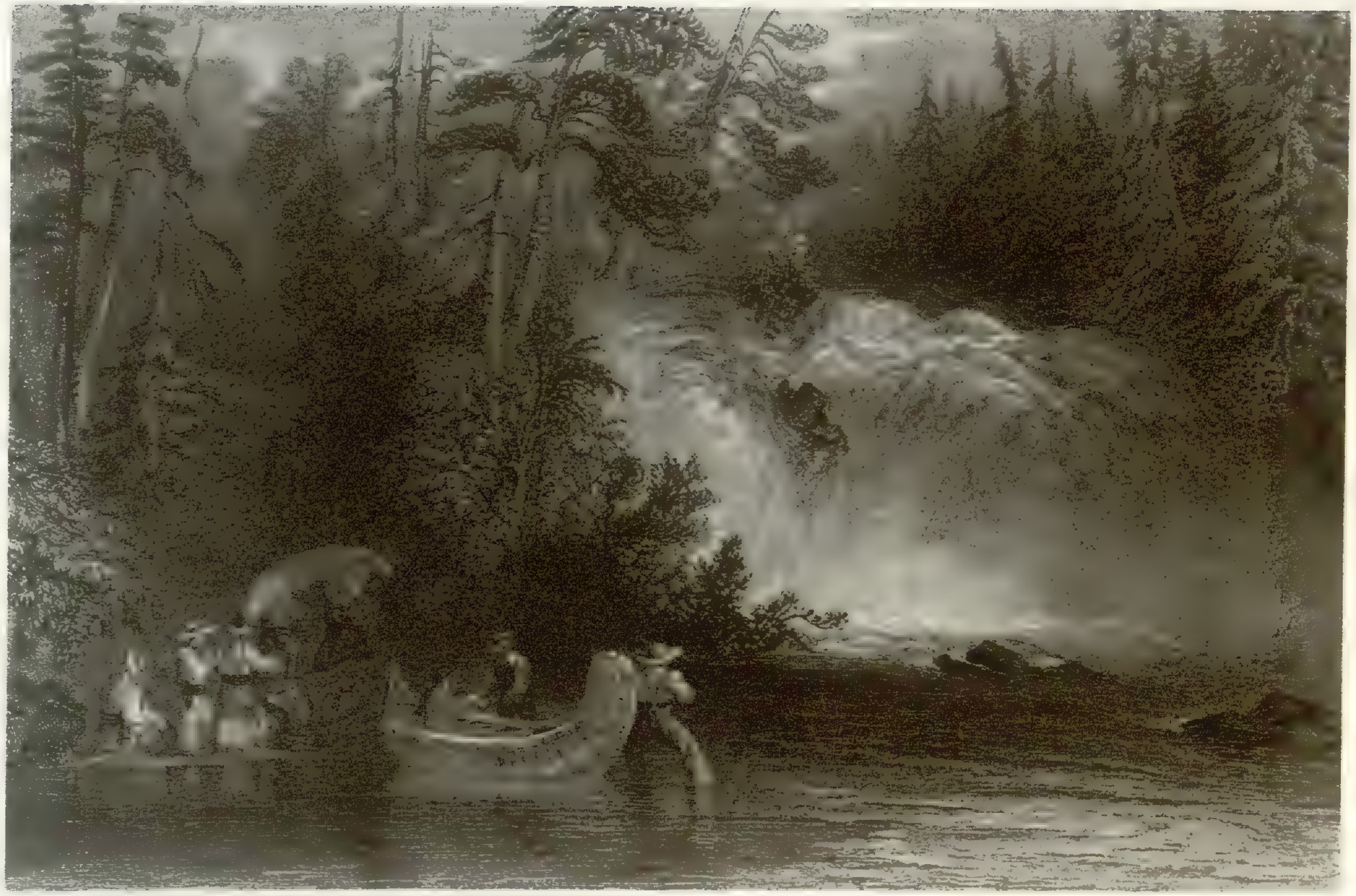


FIGURE 22

Portage des Chats on the Ottawa River, almost undisturbed by humans as seen by William Henry Bartlett. This site is highly modified for hydroelectric power generation. Canada's rivers and lakes make up at least 7.6% of its land area, some 755,000 km^2. Considerable areas of these ecosystems are modified by impoundment or withdrawal by hydroelectric dams, thermal cooling, manufacturing, agriculture, and the mining industry.

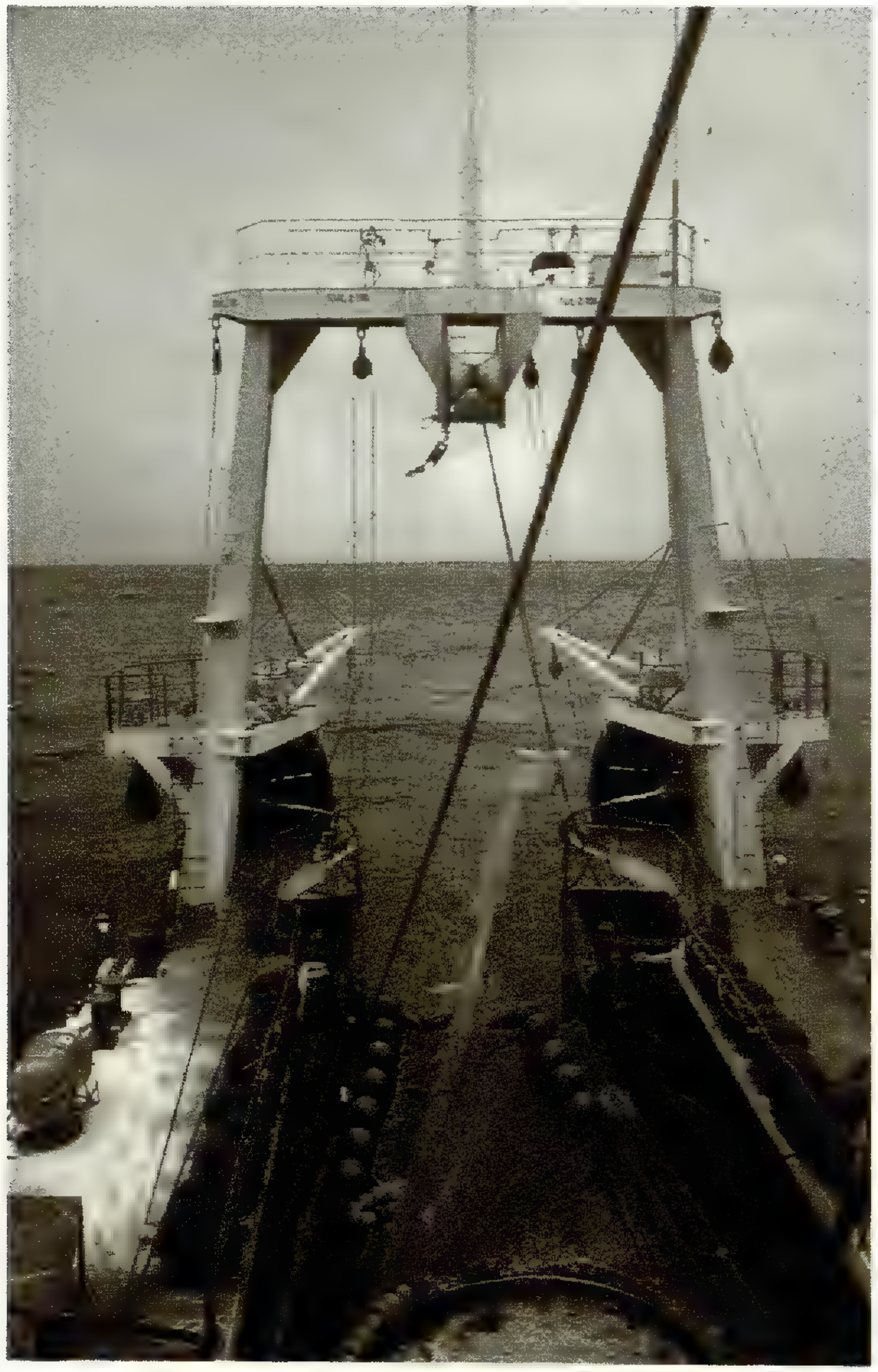


FIGURE 23

Before the recent groundfishery closure, over 35,000 km^2 of coastal shelf bottom were trawled over each year, sometimes more than once. The heavy trawl doors displace sediments on the bottom, and shear seaweeds and sessile invertebrates. Trawl door and shellfish dredging tracks total 4.3 million km on the Atlantic coast. Typically, trawl bychatches (the sea life that is discarded) are equal in tonnage to the target species. Much of the bycatch is dead or dies soon thereafter.

blooms. This includes rivers such as the Rideau, Trent, Severn, Grand, Red, Assiniboine, Qu'Appelle, Milk, South Saskatchewan, Red Deer, and Columbia. Eutrophic streams and lakes have seen major changes in vegetation, with the floating "cyanobacterial/algal mats", and spread of bullrushes and cattails (often in dense almost pure stands) thus having a major impact upon littoral zone and deeper water ecosystems. Eutrophication of water often causes serious turbidity, making it impossible for light to penetrate to deeper aquatic macrophytes, which consequently suffer major dieoffs. The introduction of exotic species to these freshwater systems have further altered their biodiversity. In southern Saskatchewan some lakes are strongly alkaline, supporting unique assemblages of species adapted to saline conditions.

Two-thirds of Canada's electricity needs are met by daming rivers to provide hydroelectric power. The placing of dams on hundreds of streams and rivers across Canada has resulted in an increase in the amount of freshwater surface (as a result of the reservoirs created). Almost any artificially regulated dam on a lake or a stream disrupts the normal functioning of the aquatic ecosystems in the affected reservoir and its immediately adjacent shorelines and uplands. Alfonso and McAllister (1994) discuss biodiversity in parts of the Great Whale River hydroelectric project. Artificially flooded lands normally cause the leaching of flooded soil with an attendant increase in mercury levels in the water and the bio- magnification of the mercury in aquatic food chains. Hydro dams change the seasonal discharge of rivers, influencing marine ecosystems in neighbouring estuaries, bays or gulfs. Normal spring discharge is reduced by dams that reduce entrainment and nutrient supply for phytoplankton. Impoundments commonly collect warm surface waters but discharge colder than seasonally normal water (drawn from the bottom of the impoundment) downstream. Many reservoirs are also managed for flood control, recreational amenities, irrigation, and other human utilitarian purposes. Unless suitable fish ladders are provided, dams impede the movement of migratory fishes. Mortality may be quite high for young fishes drawn through turbines. Dams are generally detrimental to or less than optimal for many valued species and are contrary to any goal of maintaining or restoring biodiversity or to managing a region on an ecological basis.

Aquifers across southern Canada are increasingly contaminated by chemicals from a range of sources including cottage septic systems, agricultural and industrial wastes, and toxic dumps and landfills. The contamination of the Abbotsford aquifer in the Fraser valley is but one example (Leibscher and McNaughton 1992).

5.3.6 MARINE REGIONS

With the world's longest coastline, Canada's marine areas total 6,500,000 km^2. The numbers of phyla found exclusively or mainly in marine ecosystems are greater than those in terrestrial and freshwater ecosystems as summarized in Figure 7. Thousands of species (within dozens of phyla) are adapted exclusively to marine environments. Marine waters play major roles as CO_2 sinks (Radojevic and Tressider 1992; Drenge *et al.* 1992). Evaporation from and the heat sink effect of these large water bodies have major controlling effects upon local and regional climate over large parts of Canada and upon global climate. The formation of ice and subsequent covering by snow raises the albedo of oceanic and freshwater areas (by reflecting solar energy into space). The underside of ice provides habitat for numerous planktonic and some nektonic organisms. During the summer, Canada's inland sea, Hudson Bay, has a major cooling effect extending for hundreds of kilometres inland in neighbouring provinces and territories, and modifying terrestrial ecosystems. Dense populations of plankton thrive in the cold waters off all three marine

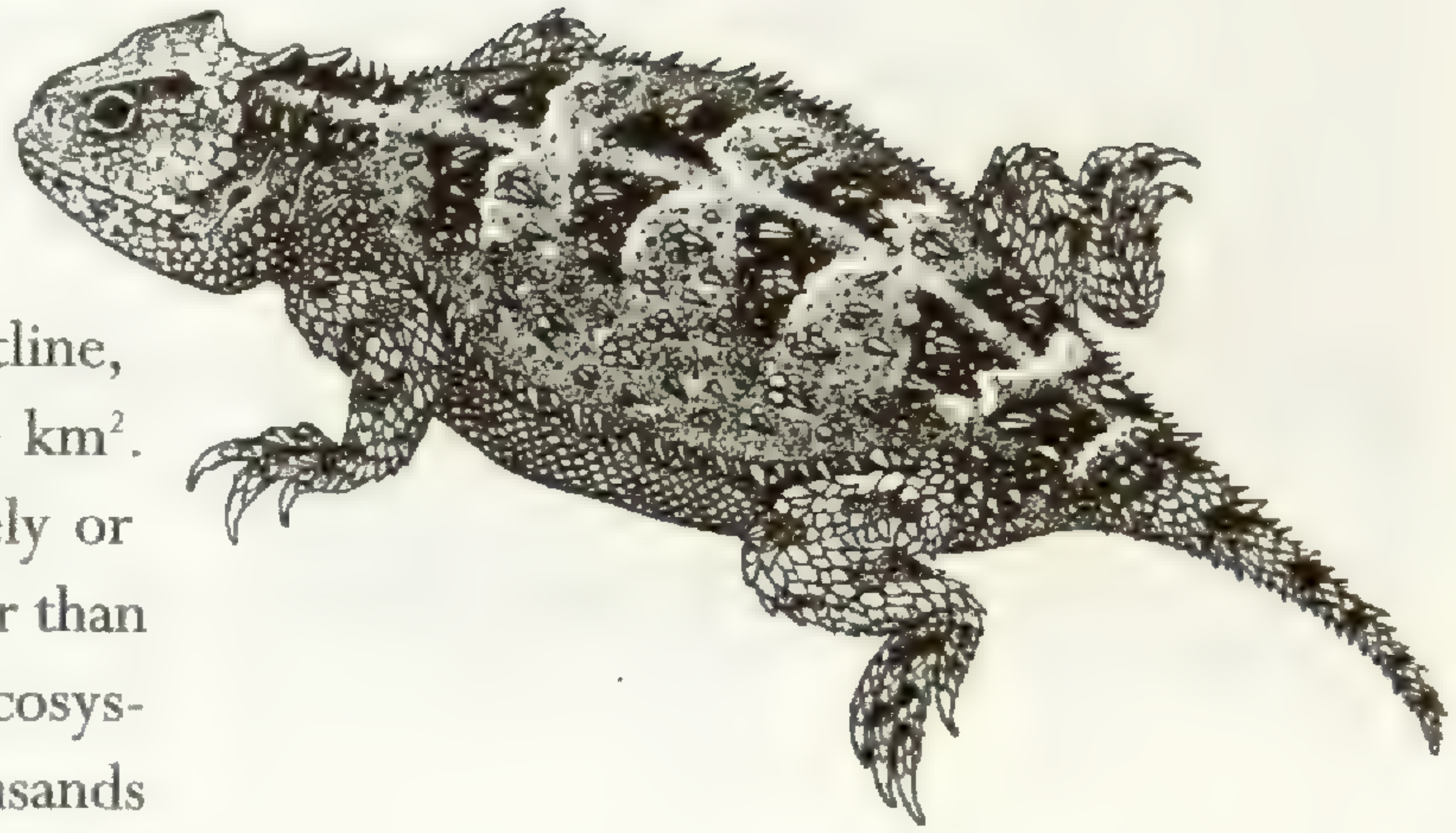


FIGURE 24

Drawing of a short-horned lizard. Short-horned lizards range north into Canada in arid areas of southern British Columbia and Alberta *(drawing by Charles Douglas from Francis Cook's* Introduction to Canadian Amphibians and Reptiles*)*.

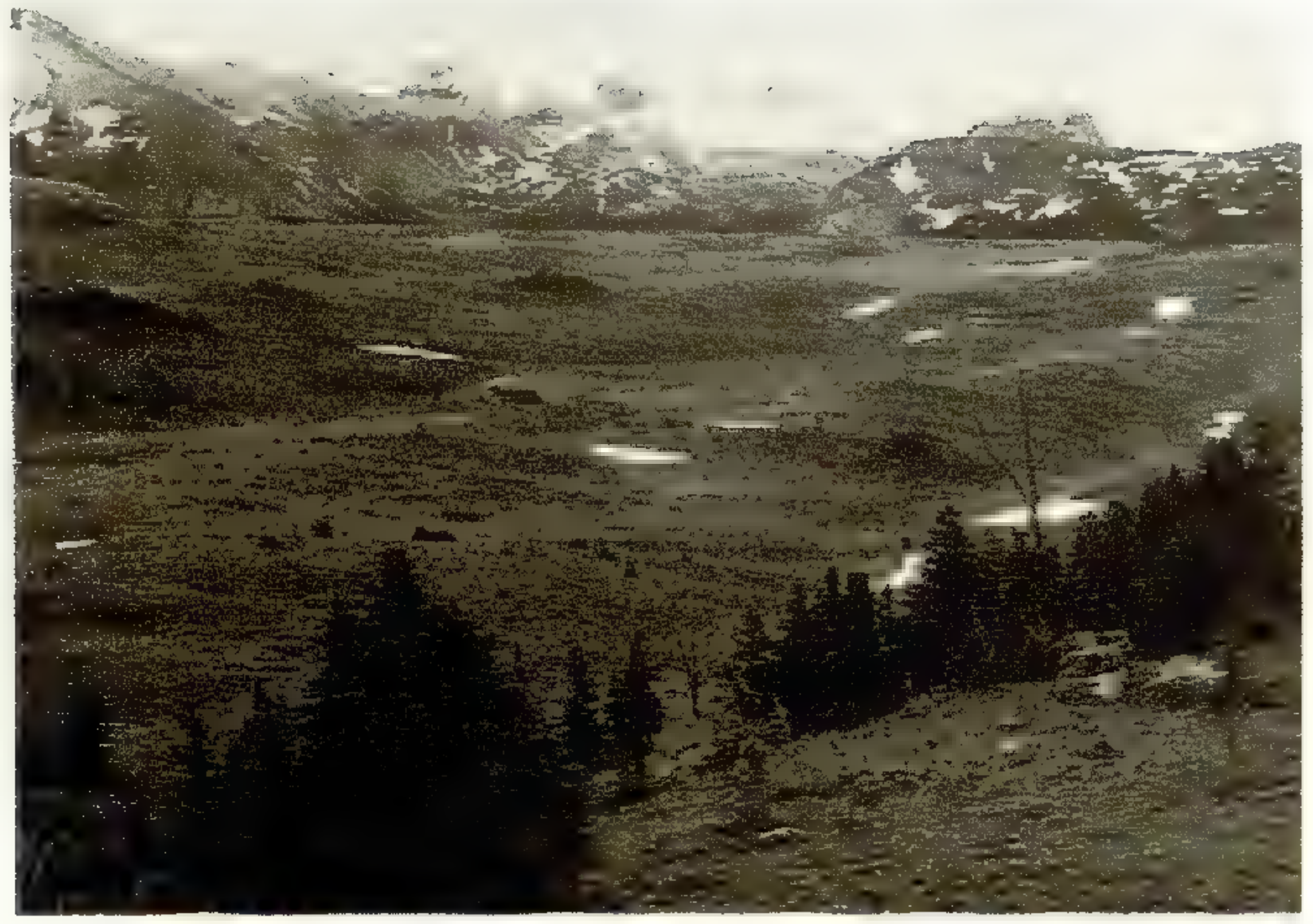


FIGURE 25

Tundra is one of Canada's major ecosystems, occupying 23% of the terrestrial land mass. While widespread across the arctic and subarctic, tundra also extends southward above the tree line in the Rocky Mountains to southern Alberta and British Columbia. Tundra in the north is impacted by atmospheric pollution. Radioactive fallout from nuclear bomb testing on tundra lichens resulted in elevated levels in caribou that browse on these fungi. Tundra are sensitive to abuse; vehicle tracks may take decades to disappear *(photo by Ted Mosquin)*.

coastlines and are vital elements in the ocean's food chains, producing a wealth of invertebrates and eventually fish, sea birds, polar bears, and important marine mammals, such as seals and whales.

5.3.7 ARID/SEMI-ARID AREAS AND DESERTS

In almost 10,000,000 km^2 of territory, Canada has few true deserts—those areas receiving less than 250 mm of precipitation per year and where plant growth is limited by water rather than temperature (Karstad 1979, 100). The warm arid/semi-arid areas occur only in small rainshadow areas in the lowland valleys of southern British Columbia, the driest of which is located around the border town of Osoyoos. The "Osoyoos desert" is home to species uniquely adapted to parched conditions. The short-horned lizard and rock wren, typical of the Great Basin Desert, are found here.

As well, small patches of arid lands occur in southern Alberta and Saskatchewan where yucca, the short-horned lizard, and the prairie rattlesnake are found. In northern Saskatchewan a small area of Athabasca sand dunes has a desert-like appearance and contains species endemic to this sandy site. But its rainfall regime is no different than that of surrounding boreal forest. In southern Manitoba the Carberry Sandhills are likewise very desert-like, harbouring some species that occur in the hot and dry parts of the Great Basin of Utah and California (e.g. the grass, *Oryzopsis hymenoides*). The Great Sand Hills of southwest Saskatchewan cover nearly 2,000 km^2 and provide habitat for some 215 native species of vascular plants (Ledingham 1992). Although desert-like, areas like the three mentioned above receive considerably more rain than deserts. These outlying areas typically support a variety of invertebrate and vertebrate species common in the deserts and dry prairies of the western United States and that are indicators of arid conditions. Hence, the chances of (non-migratory) species living in these kinds of specialized ecosystems being *physiological endemics* are high. From a management perspective, in all such cases, one should assume that once the local race is extirpated, successful reintroduction from colonies to the south may prove to be difficult or impossible.

5.3.8 TUNDRA

Next to the forested areas of Canada, the largest sectoral ecosystem is tundra, occupying 2,303,000 km^2 or 23% of the terrestrial area. Biodiversity in the tundra is the lowest in average species per unit area. Permafrost is close to the surface, and drainage is poor. Hence, tundra ecosystems tend to be wet in summer, but frozen solid in winter. Tundra ecosystems range around the globe and, likewise the large majority of their species have extensive continental distributions or are circumpolar. Hence, areas harbouring endemic species are fewer and more generalized. However, in cases where widely ranging tundra species extend far southward in alpine areas along mountain chains (as in the case of the Rocky Mountains), one would expect to see the evolution of unique physiological, ecological, and morphological endemics.

Tundra is sensitive to vehicle traffic and recovery takes decades. Atmospheric pollution is a concern not only because of the toxic substances but because the resultant smog blocks sunlight. Radioactive fallout from nuclear bomb tests and the Chernobyl reactor accident has accumulated in lichens and resulted in elevated levels in caribou of strontium-90 and caesium-157 (Environment Canada 1991c).

5.3.9 SPECIALIZED ECOSYSTEMS

In a country as large as Canada, many types of specialized ecosystems exist where unique species inevitably occur. Included are salt marshes, intertidal marine shorelines, steep escarpments, such as the Niagara Escarpment of Ontario site of the oldest trees in eastern Canada (small white cedar, *Thuja occidentalis*, over 500 years old), localized calcareous fens of southern Ontario, alvar, spray zones along the shorelines of Lakes Superior and Huron, local sand dunes, and others.

Two types of highly specialized (and localized) ecosystems are caves and hot springs. Cave habitats are found primarily in limestone areas of the country. In areas of North America that were not glaciated, unique cave faunas may develop. Blind amphipods of the genus *Stygobromus* occur in caves in Banff National Park, Alberta, and Vancouver Island, B.C. The small size of caves means that they are extremely vulnerable to impact.

Hotsprings occur occasionally throughout British Columbia and contain varying numbers of plant, fish, and invertebrate species such as distant northern outposts of ranges far to the south, or even (in the case of fishes) exotics introduced from the tropics (Crossman and McAllister 1986; Burnett *et al.* 1989; Williams and Danks 1991). The Liard Hotsprings is home of an endemic snail (Topping 1992) and a lake chub (*Couesius plumbeus*) variety that may represent an undescribed species. Some hot spring areas (e.g. Radium Hot Springs) have been almost completely destroyed by commercial development and their unique species have been lost, or survive as individuals under the most tenuous and risky of circumstances (Burnett *et al.* 1989).

5.4 HABITAT/ECOSYSTEM STATUS AND CHANGE OVER THE PAST 20 YEARS

Appendix 3 attempts to estimate the losses of natural ecosystems/habitat in each of the seven sectoral ecosystems of Canada. Natural systems over large regions have been lost to agriculture, urban areas, industrial activities, and more recently, by forest managementregimes which may include burning of slash and soil following logging and the application of herbicides (Harris 1984).

About 13% of the southern half of Canada (former forest and grasslands) has been converted to agriculture since European settlement. In 1986 the total area of Canada's farmland was 678,000 km^2 (Statistics Canada 1992b). This included 332,000 km^2 under crops; 36,000 km^2 of improved pasture; 90,000 km^2 under summer fallow; 8,000 km^2 under other improved land use and 218,000 km^2 of "unimproved" land. In some areas the conversion of extensive land has been almost 100%. This has occurred most particularly in southwest Ontario, in parts of the prairies, and the valleys of southern British Columbia. Other areas still retain patches of original forest or prairie but variously altered, as for example, south eastern Quebec, eastern Manitoba, the prairie parkland, the dry prairies of southwest Saskatchewan and southern Alberta and the Peace River region. In the past 20 years, losses of natural ecosystems through direct conversion to agriculture have occurred through land clearing mainly in the Peace River area, northern British Columbia, and eastern Manitoba.

In some regions, especially rural areas of Ontario and Quebec, farmland continues to be abandoned. In such areas natural succession is slowly returning normal biodiversity functions (see Chapter 4). Likewise, urbanization is clearly the cause of conversion and fragmentation of natural forested ecosystems around major cities and towns like those in the Oshawa to Windsor axis in Ontario, in the valleys of interior British Columbia, and around cities like Calgary, Vancouver, and Victoria, which are now receiving the brunt of population increases. On a broader scale, Canada's expanding highway and road system is a major cause of habitat fragmentation and associated wildlife loss. New roads into the western Arctic and Hudson Bay regions will probably give birth to new road networks and the further loss of natural systems.

FIGURE 26

Mature temperate rainforests such as this one on the Queen Charlotte Islands, British Columbia, now occupy only a small fraction of their former range *(photo by Ted Mosquin)*.

Clearcut logging in most provinces is continuing and even accelerating, affecting the quality and distribution of Canada's natural forests. This form of logging brings about a drastic conversion of forested land to an earlier stage of succession. Given time—measured in many hundreds of years—these clearcuts will largely return to normal biodiversity conditions provided that ecological and environmental conditions remain stable and do not deteriorate significantly.

Some idea of the continuing attrition of natural forests in Canada comes from a study of changes in the extent of unroaded wilderness in the country between 1970 and 1988 (Chipeniuk 1989). Chipeniuk carried out a province by province review of new road cutting into remaining forested wilderness areas and reported extensive new roaded areas in most Canadian provinces over this 18-year period. He defined wilderness as areas of land and water not crossed by public roads or approached by them any nearer than 16 km. Area losses are greatest along the roaded/unroaded frontier—meaning closer to towns and cities. Canada's roadless areas are *de facto* wilderness areas, and all are potential candidates for new roads and development. There is little formal protection, and no constraints or restraints on road building were identified. Roads by themselves are seldom subject to environmental impact analysis. He notes: "Anyone who thinks Canada is still a thin band of settlement hard against the American border should study the maps. The cultural frontier has moved a long way north."

A matter of considerable recent concern to biodiversity is the rather loose use of the term "reforestation". In regions where tree diversity is great, the widespread planting of single species over large areas has the effect of gradually converting complex forested ecosystems into plantations with far fewer species and even to monocultures. In many such areas we see the incremental alteration and attrition of existing biodiversity through herbicide spraying and other abnormal prescriptions. Such "stand conversions" can be particularly destructive along the coast of British Columbia, where clearcutting, followed by slash burning, soil erosion, and leaching of nutrients forces major losses of native species. As well, in many forest areas herbicides are deliberately applied to control entire groups of plants and this in turn affects dependent animals. More than 90% of plants in Canadian forests are non-tree species. Forest management plays minimal attention to these herbs and shrubs. These kinds of impacts, when extended over large regions, cause significant reductions in the quality and nature of biodiversity over time (Hammond 1991; Boyle 1991).

To our knowledge, no large-scale forest ecosystem restoration projects have been undertaken in Canada, not even in National Parks where a case for such restoration could now be made on the basis of a clause in the *National Parks Act* which requires Parks Canada to maintain ecological integrity. Many small scale "reforestation" projects have been taking place on abandoned farmland in some formerly forested areas (e.g. county forests in southern Ontario). However, the goal of these projects has been future wood production and not the restoration of biodiversity or ecological integrity. Planting of one or two species continues to be carried out in clearcut areas, as for example in northern Ontario and in central and coastal British Columbia, but again, the goal is stand conversion to more economically desirable tree species. However, a new awareness of hazards of stand conversion is emerging (Hammond 1991). In Europe where stand conversion has been considered for centuries by foresters as a virtue, monoculture forests have witnessed significant reductions in productivity, apparently due to losses of mycorrhizal and other soil organisms from the forest floor (Hawksworth 1991a, 1992; Cherfas 1991). Acid rain and airborne nitrogenous agricultural fertilizers have also been implicated in these regressive forest trends.

In Canada, little is known about symbiotic relationships between fungi and forest trees. The practices of clearcutting and systematic burning of "debris" and sod (where mycorrhizal fungi live) as well as the broadcasting of chemical herbicides and fertilizers may be setting the stage for permanent harm to productivity of future forests (Fyles and Feller 1991; Hutchinson and Meema 1987). Acid rain and the concomitant release of aluminum is known to affect woodland lichens and mycorrhizas of Jack Pine (Hawksworth 1990; Browning and Hutchinson 1991). Obviously, some anthropogenic impacts on symbiotic relationships can be more readily avoided than others.

Losses of Canadian grasslands amount to some 60% (Environment Canada 1991c) or 80% of the original (World Wildlife Fund 1989). The bulk of grassland losses occurred during the great plowdown of the wild prairie during the last part of the 19th century, early part of this century and continuing up to this day. During the past 20 years losses continued due to the planting of alien grasses to replace native flora in rangelands of Saskatchewan and Alberta (Table 5). Grassland has also been lost in the aspen parkland due to the invasion of forest following the control of free fires. As noted in the previous section, attempts at restoring some

FIGURE 27

Photo of a lichen and a gray tree frog, *Hyla versicolor*. Acid precipitation affects thousands of square kilometres of southern Canada. It has contributed to the loss of lichens on land, freshwater fishes and molluscs, and amphibians, especially in Ontario, Quebec, and the Maritime provinces. Its effects on soil organisms and trees is suggestive of much more far-reaching impacts *(photo by Don McAllister)*.

prairie are being contemplated or being made in Grasslands National Park and through a private initiative in Manitoba (tall grass prairie).

Wetland losses are almost all due to conversion of wetland ecosystems for agriculture, although recently urbanization and golf courses have begun to take their toll. McCullough (1981) estimated that from the Niagara River to Oshawa, 83% of the original marshland has been destroyed or degraded. The losses are continuing today due almost entirely to a lack of a firm policies on wetland protection and the existence of programs to subsidize drainage. For example, Environment Canada (1991c) reported that 7.9 million hectares were already drained for agriculture, but another 8.2 million hectares were "still needing drainage". Further, 35% of the original wetlands along the Canadian shores of lakes St. Clair, Erie, and Ontario have been destroyed. For the prairies, Gauthier and Henry (1989) estimate that 40% of wetlands have been drained for agriculture. Losses of wetlands are continuing according to the North American Waterfowl Management Plan (1987). In the maritime provinces 65% of the tidal and brackish marshes have been drained or filled in; 70% along the lower Great Lakes and St. Lawrence River, and 70% of the Fraser River marshes (Shay 1981). Some nongovernmental organizations, notably Ducks Unlimited (DU), undertake projects across Canada to improve wetland habitat for waterfowl. DU's efforts to create new wetlands where none had been before have broad support. However, there is considerable resistance in the conservation community generally to proposals aimed at channelizing, dyking or otherwise artificially controlling natural wetlands that are already self-regulating and productive.

Freshwater ecosystems across Canada are likewise experiencing changes for the worse, although there are notable exceptions where the negative trends have been reversed—at least in the short term. Losses of, or changes to lake biota are due to several factors. Acid rain, widespread in many parts of Canada (McNicol *et al.* 1987; Environment Canada 1991c), has caused extirpations of fish from thousands of lakes in Ontario. Large regions of Canada are not buffered against acidification by limestone or similar sedimentary bedrock. The effect of acid rain is widespread because some 46% of Canada's land and freshwater surface has little capacity to buffer acidity (Environment Canada 1991c). Most of these acidified lakes have also lost their molluscs and amphibians; planktonic flora and fauna will also have been changed or largely eliminated. In some regions governments have taken meaningful action to reverse these negative trends (Environment Canada 1991b).

Until the 1970s these large freshwater bodies received incrementally greater inputs of fertilizers, toxins, sewage, and other contaminants from expanding adjacent towns and cities, industries, cottages, farms, and regional municipal sewers and dumps (Nrigau and Simmons 1984). At the same time, the biodiversity in the lakes was being affected by more boat traffic, the continuing introduction of exotic species such as sea lampreys, carp, alewife, and rainbow smelt. Catches of valued coldwater ciscoes and lake trout dropped, while catches of rainbow smelt (*Osmerus mordax*) and Pacific salmon (*Oncorhynchus* species) increased. Native molluscs and deepwater sculpins (*Myoxocephalus thompsoni*) decreased. Several ciscoes and the blue walleye (*Stizostedion vitreum glaucum*, sometimes referred to as blue pike by Lake Erie fishermen) became extinct. Fish kills were common, carcinomas increased, and sex hormone changes took place in some colonial nesting birds, causing major reproductive failures at nesting sites. Toxic substances cause developmental abnormalities and damage to chromosomes in fish and other aquatic organisms (Al-Sabati 1991). In the 1970s, as a result of the Boundary Waters Treaty and the Great Lakes Water Quality Agreements (which started in 1972), corrective actions on certain toxic chemicals were slowly initiated by Ontario and states bordering the lakes.

Over the past 20 years, Lakes Erie and Ontario have seen reduced chemical contaminants and nutrient loading thanks to new programs (Environment Canada 1991c). The level of some of the 500 toxic compounds (Nrigau and Simmons 1984) in the Great Lakes, such as PCBs, has fallen due to efforts to reduce toxification and eutrophication. The recent introduction and spread of the Zebra Mussel, *Dreissena polymorpha* (Table 5), is causing serious concern for the future of the organisms and ecosystems of the lakes. It pre-empts significant benthic habitat and filters out an enormous volume of plankton on which other species depend. There is continuing concern about the future of the lakes with respect to water quality and biodiversity (Heritage Resources Centre 1992; Mills *et al.* 1993). For example, levels of the toxic furans and mirex are now increasing in sports fish of Lake Ontario according to the 1993 *Guide to Eating Sports Fish* published by the Ontario Ministry of the Environment.

There is accumulating literature on quality of freshwater bodies in many parts of Canada (Environment Canada 1991c) and changes to their biodiversity can be expected. With the exception of certain classes of chemicals in freshwaters, the general trend is still toward incremental degradation. Specific policy decisions of the federal and provincial governments allowing offending chemicals to be manufactured and released into natural systems are at the root of the deterioration. Examples are: recent decisions of provincial governments to promote construction of large polluting pulp mills in new areas across boreal forest regions of Canada; the Green Plan goal of zero discharge of persistent toxic substances not being accompanied by a target date; the continuing manufacture of synthetic toxic chemicals, and many other actions have inevitable consequences to water quality and to the abundance and quality of dependent biodiversity and biological resources. Since toxic chemicals play such a major role in the destruction of biodiversity, it is worth providing the definition of "toxic substance" used by the International Joint Commission (1994) in its assessments of this very serious matter. Toxic substance means: *a substance which can cause death, disease, behavioural abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions or physical deformities in any organism or its offspring, or which can become poisonous after concentrations in the food chain or in combination with other substances.*

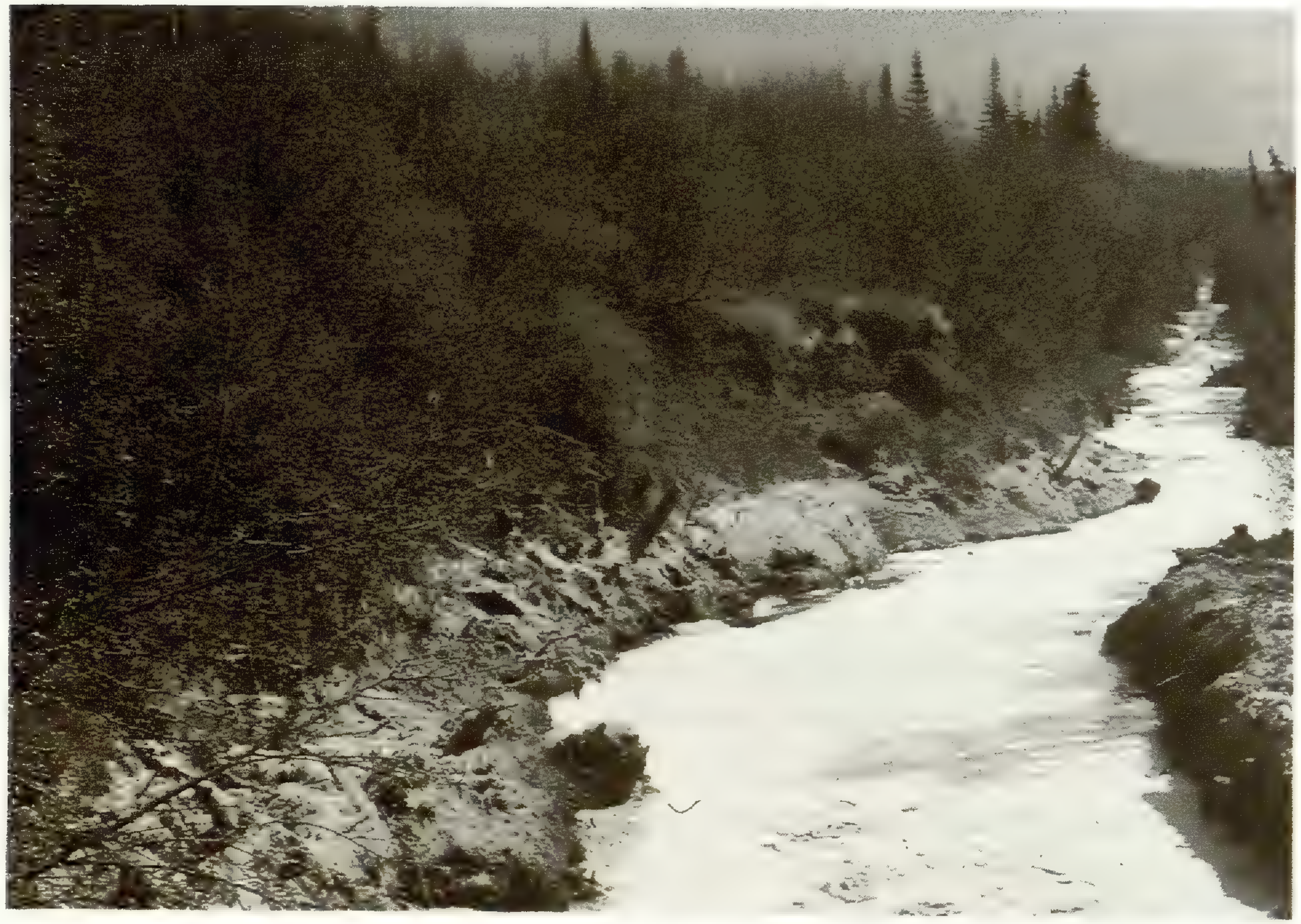


FIGURE 28

Pulp effluent from a paper mill on the north shore of Lake Superior. Pulp mills are a major cause of toxification of Canada's lakes, rivers, and marine coastal waters *(photo by Ted Mosquin)*.

The changes in river biota are less well documented in the scientific literature. However, one can take almost any average river or large stream in the more settled parts of Canada and examine historic records of aquatic resources from the days of early settlement. Such comparisons of fish, frogs, waterfowl, shorebirds and other biota will usually reveal that these rivers and streams have undergone dramatic changes—usually extirpations and large reductions in species utilized by early pioneers. Regretfully, such accounts often read like a requiem. Marquis *et al.* (1991) documented decreased fish landings in the St. Lawrence River between Cornwall and Trois Pistoles. The decline began in the mid-1950s. They attributed the decline to landfills, riverbank habitat shrinkage due to human population increases, habitat degradation due to dredging and dumping of dredged material. The freshwater mussel fauna (*Unionidae*) of the Sydenham River drainage in southwestern Ontario has decreased from 33 species, subspecies and forms in 1937 to 13 in 1985 according to Mackie and Topping (1990), who attributed the loss to lowered substrate and water quality, due in part to the cutting of an extensive agricultural drainage network in the basin.

Hundreds of rivers and larger streams

across Canada have been dammed for hydroelectric power, to increase recreational amenities, or for flood control, thus greatly modifying or even eliminating the seasonal rhythms of these water systems and impacting on the dependent shoreline flora and fauna. Biotas in impoundments are obliged to adapt from riverine to artificially managed lacustrine systems or they disappear. Populations of shallow-water species are reduced by fluctuating water levels in the impoundments, and subsequent drying and freezing. Seasonality of the flow downstream as well as summer temperatures are changed, migration routes usually blocked. Some riverbeds dry up when their flow is diverted, and toxic mercury (released from flooded soils and vegetation in the impounded areas) moves up the food chain into fish, fish-eating wildlife and humans.

The Atlantic and Pacific coastal and offshore marine areas are experiencing contamination and loss of biota due to degradation of habitat from impacts of industrialization, ocean dumping, coastal development, and severe overfishing (Messieh *et al*. 1991; Wells and Rolston 1991; Harding 1992; Norse 1993). The degradation of estuarine and near shore marine ecosystems is often severe. For example, for many decades the Gulf of St. Lawrence has been receiving the entire panoply of toxic metals, municipal sewage, garbage, agricultural runoff and various industrial discharges from rivers and streams of the St. Lawrence River basin. Aluminum smelters, pulp companies and the like are allowed access for their industrial effluents to waters of the Gulf, contaminating area fisheries, threatening the troubled beluga whale population with extirpation, and altering the fabric of marine life in the Gulf. Béland (1990) reported very high levels of PCBs, DDT, and Myrex in the blubber of these belugas, in the milk of females, and in suckling and recently weaned calves. In B.C., shellfish beds have been closed due to pulp mill effluent being dumped into shoreline waters in enormous volumes with the approval of the provincial government. Along both the Pacific and Atlantic coasts, industrial trawling or "dragging" has also been a major cause for concern over the past decade. The federal government policy aimed at maximizing the short-term return on resource harvest has caused a catastrophic collapse of the Grand Banks marine fisheries. Trawling fishes and shrimps and dredging for shellfish modify benthic ecosystems through removal of or damage to seaweeds and sessile invertebrates such as sponges, sea anemones, urochordates, crinoids, and tube worms (McAllister 1991c). Habitat destruction, sometimes multiplied by two or more passes of trawls per year removes shelter for smaller species and young of large species. Bycatches, the unwanted species discarded from trawl catches, commonly comprise 50% of the take. This impacts biodiversity, and the large biomass discarded and killed affects ecosystems. According to Environment Canada (1991c), 35,000 km^2 of Atlantic coast shelf are affected by 4.3 million km of trawling and dredging tracks. The disposal of bycatch favours gull populations at the expense of other sea birds.

According to Harding (1992), 685,000 metric tons of groundfish, 359,000 tonnes of pelagic fish, and 228,000 tonnes of shellfish were marketed from the east coast of Canada in 1989. That totals 1.3 million tonnes. If the bycatch equals the retained catch, then each year 2.6 million tonnes of fish and invertebrates are removed from the east coast fishing grounds, or dumped overboard dead or injured. Supposing a modest 50% mortality in the bycatch, that means that a minimum of 3.2 million tonnes of biomass were removed or killed in 1989. The effects of such a large catch/mortality on the east coast shelf ecosystem and biodiversity should be determined.

In Arctic marine regions, localized industrial effluent discharges have resulted in

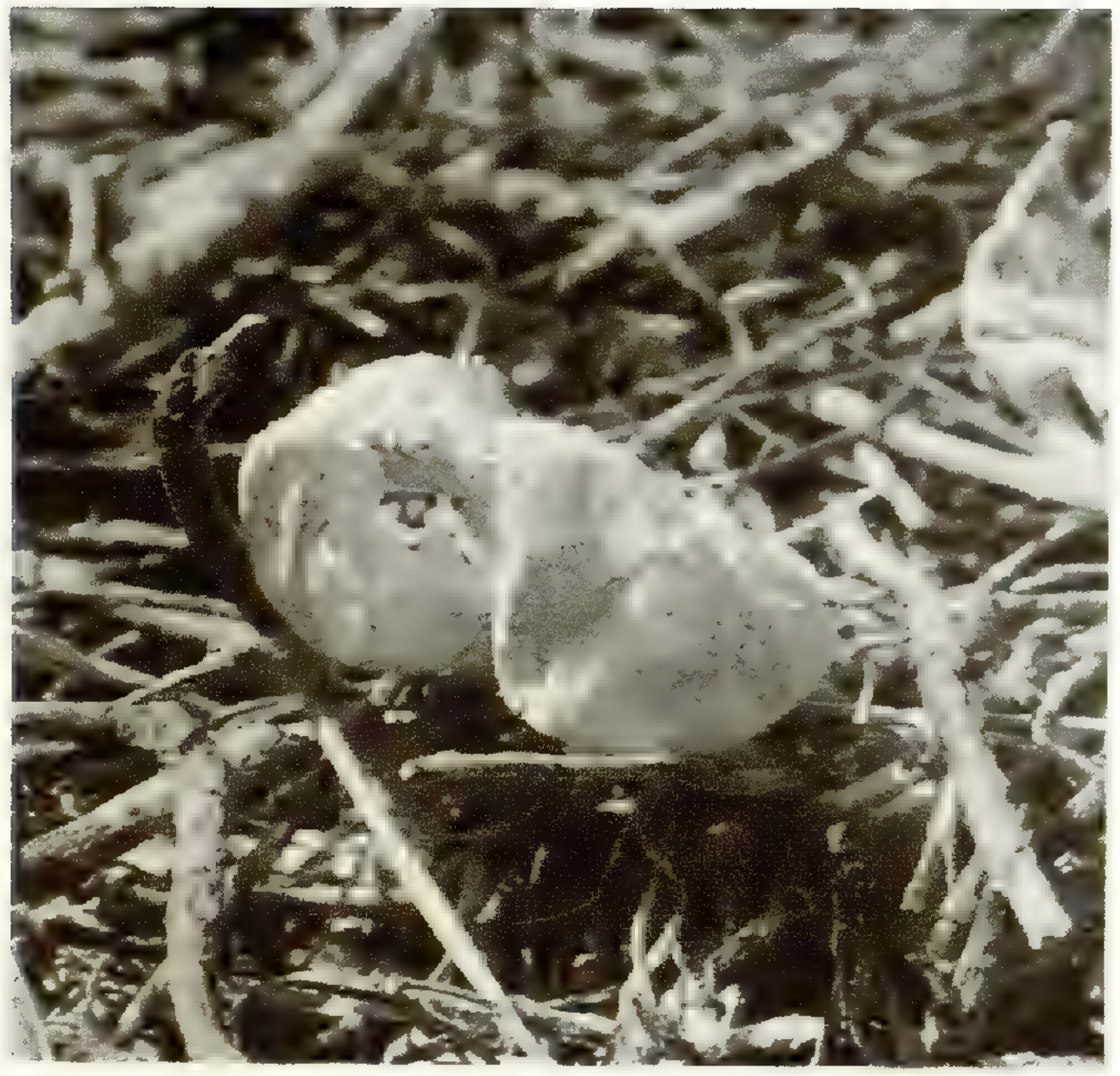


FIGURE 29

Photo of a thin pelican eggshell. Eggshell thinning or loss caused by DDT and other chlorinated fluorocarbons has been a major cause of declines in Brown pelicans, terns, eagles, and other fish-eating birds. This trend has now been reversed and many species are again producing eggs with normal shells. In other species, biomagnification, the concentration of toxicants up the food chain, is still at work. In Polar bears, *Ursus maritimus*, PCB levels are two billion times higher in the liver than in the sea water habitat *(photo by Bob Risebrough)*.

elevated concentrations of metals, PAHs and other hydrocarbons in sediments and biota. More dangerous to Arctic ecosystems, however, is the long-range transport of pollutants borne by air and water that are increasingly contaminating Arctic food chains. Atmospheric transport from Europe and North America brings hundreds of alien chemicals into the Arctic ecosystem. Many of these chemicals move up the food chain and become intensely concentrated in the tissues of seals, polar bears, and walruses (Norstrom and Muir 1988a; Norstrom *et al.* 1988b), bringing unacceptable levels of toxicity into the natural foods of peoples of the north and magnified levels in breast-milk.

It is also likely that the growing number of hydroelectric dams around Hudson and James Bays are affecting marine, estuarine, and associated freshwater ecosystems. Such changes to biodiversity along these coastlines can be expected as a result of disruptions of the annual hydrological rhythms of rivers where the annual interplay between salt and fresh waters have determined the nature and abundance of biota. McAllister (1991b) indicates that winter freshwater runoff into Hudson Bay may be increased by some 50%. At the same time, summer flow of fresh waters is reduced due to the re-filling of reservoirs. These major artificial rhythms affect ice break-up and formation, entrainment of nutrients, movements and occurrence of biota, and life cycles of food chain species. Alfonso and McAllister (1994) evaluate the potential impacts of hydroelectric projects on biodiversity in the Great Whale River basin and coastal areas.

While these oceanic regions are very large, they are by no means secure for the survival of marine biodiversity. A detailed description of the declining ecological health of these marine areas off Canada's coasts, and including the accumulating toxic chemicals in Arctic mammals is provided by Norse (1993) and by Wells and Rolston (1991). Habitat destruction and overexploitation of marine fisheries are primary causes of the decline of the productivity of Canada's marine areas. As well, estuaries and salt marshes, which are essential nurseries for a wide range of sea life continue to be degraded by pollution or converted to human uses, as for example the Fraser River estuary where pollution, airport runways, and floating log booms continue to decrease the quality and area of this estuary.

5.5 SIGNIFICANT CHANGES IN POPULATIONS OF SELECTED SPECIES OF IMPORTANCE OVER THE PAST 20 YEARS

To draw conclusions in a large northern country like Canada about any major changes in species abundance over the past 20-year period needs to be done with careful attention to available systematically collected or documented information on species and ecosystems. Except for species that are valued as biological resources, there is only scattered formal monitoring and census documentation, with an emphasis on higher organisms, humans, and commercial species. Information received from some provinces is suggestive of the sorts of changes that are being variously documented. Some of the changes could be due to cyclic phenomena such as spruce budworm outbreaks or to invasions of exotics such as the gypsy moth in southern Ontario. When systematic field observations are available, the information is more reliable. One example of where information is available comes from the Northwest Territories where a 53% increase in muskoxen has been documented over 10 years.

A number of monitoring programs have been developed in Canada in an effort to determine trends in wild species. The Breeding Bird Survey (BBS) conducted by the Canadian Wildlife Service (CWS) is an example of ongoing monitoring of wild bird populations (Erskine *et al.* 1989). The Christmas Bird Count carried out by the CWS and the U.S. Fish and Wildlife Service in co-operation with volunteers from many environmental groups in cities and towns across the country is another. Data on trends take many decades to accumulate. The CWS recently examined approaches to monitoring biodiversity of vertebrates in the Lake Ontario watershed (Premak 1993).

A recently emerging problem is the shooting of grizzly and black bears to obtain gall bladders and claws for the oriental folk medicine market. The spreading use of all terrain vehicles and 4x4s coupled with major cutting of new road networks into wilderness of B.C., Alberta, and into other wild lands where these large carnivores still live are known to be causing decreases in the numbers of these native species (Hummel and Pettigrew 1991). The increasing number of small, one-person, high speed motor boats is causing concern regarding the nests and nestlings of water birds.

Populations of some previously rare species and populations are known to have recovered (Dauphiné 1989; World Wildlife Fund 1991). For example, the total number of gray whales on the Pacific coast has increased from a low of only 2,000 to 19,000, attesting to the power of simple government policy changes. Likewise, the White Pelican has now been delisted by COSEWIC, due to recovering populations.

It is impractical in a country the size of Canada to monitor population trends in even its rare, vulnerable, or endangered species. However, since species cannot survive without the ecosystem that produced them, conclusions about the status of many such species can be drawn from observations on the state and trends in the quality and extant of required ecosystems. The question of minimum size standards for parks, nature reserves, and other areas where normal biodiversity can be protected is now receiving considerable attention in Canada (Poser, Crins and Beechey 1993—esp. papers by T.D. Nudds, J.B. Theberge and G.J. Forbes).

One of the most serious declines known to be taking place now is in woodland bird species, due to extensive and accelerating deforestation in Central and South America, coupled with ongoing clearcutting and/or fragmentation of forested landscapes in southern and boreal Canada. Fragmented landscapes greatly increase the amount of predation on woodland birds and their young as well as the amount of cowbird parasitism of nests in nesting territory in both the

United States and Canada (Scott and Ankey 1980; Terborgh 1992). Cowbird parasitism is extremely widespread in areas of fragmented forest such as is found over large areas of southern parts of Canada. One female cowbird is known to lay as many as 40 eggs in a single summer.

Table 7 lists groups or species that have experienced significant changes in population levels in the past 20 years. Information is drawn from various sources.

TABLE 7

SPECIES AND GROUPS IN DECLINE IN CANADA

Migratory Birds	**Other Species and/or Groups**
Rose-breasted Grosbeak	All small parasitic wasps (catastrophic collapses of populations of many species)
Ovenbird	Almost all butterflies
Veery	Grizzly Bear (due to new roads and poaching)
Gray Catbird	Atlantic Cod, Atlantic pollock, Tuna
Northern Waterthrush	Lake Charr
Woodthrush	Atlantic Groundfish and Redfish
Gray-cheeked Thrush	Pribiloff Fur Seal (due to overfishing of their required food)
Swainson's Thrush	Other overfished marine species
Nashville Warbler	Marbled Murrelets
Brown Thrasher	Lichens
Rufous-sided Towhee	Frogs
Red-eyed Vireo (other vireos as well)	Salamanders
Acadian Flycatcher	Fishes, molluscs, crustaceans and other invertebrates in acidified Ontario and Quebec lakes
Black-and-white Warbler, Parula Warbler, and most other warbler species	Sage Grouse (Saskatchewan)
Yellow-billed Cuckoo	Puffin species on east and west coasts
White-throated Sparrow	Pearly Mussel (numerous species)
Baird's Sparrow	
King Rail	
Hanslow's Sparrow	
Piping Plover	
Long-billed Curlew	
Marbled Godwit	
Prairie Falcon	
American Avocet	

Thousands of lakes in Ontario and Quebec are now essentially bereft of fish, amphibians and molluscs, crustaceans, and other small invertebrates (McNicol *et al.* 1987; Environment Canada 1991c). Lichens are widely known to be indicator species of the severity of acid rain. Most lichens cannot survive acid rain or other atmospheric pollution. The large-scale disappearance of lichen biodiversity has been noted in urban and industrial areas of Ontario and Quebec (Brodo 1992). Most sensitive to atmospheric pollution are the "macrolichens" such as *Bryoria, Parmotrema,* and *Usnea.* To find out whether such losses of lichen species have occurred since the turn of the century, Wong and Brodo (1992), using the Canadian Museum of Nature's CURATOR data base of lichen specimen data, examined which lichens had not been collected in recent years. The hypothesis was this: given the intense level of collecting by Wong and Brodo (1960-present) and by Roy Cain and colleagues (1930-1960), an assessment of the disappearance of lichens from the lichen flora can be made simply by comparing the list of lichens known prior to 1930 with the list from the post-1960 interval. It was found that of the 465 species recorded in southern Ontario, 42 have not been collected since 1930 and an additional 10 have not been collected since 1960. Thus, the lichen flora has suffered an 11% decrease in total species since the turn of the century. Wong and Brodo note that while it is possible that some of the very small lichens may have been overlooked, this is not the case for foliose and fruticose species, which are large and which appear to have completely disappeared in the past 60 years. This is a serious loss of biodiversity, and does not measure the reduction in abundance and reduced ranges of most lichen species and what must be major losses of genetic diversity at the population level. As well, reduction in nitrogen fixing lichens would impact upon the floral, microfloral and microfaunal components of local and regional ecosystems. The trend toward the complete loss of lichens over large regions of North America continues.

Other groups with major decreases are some insects. For example, parasitic wasps (wasps that prey upon other insects) were extremely abundant as recently as the early 1970s but are now rare or absent in the same habitats. Masner has been studying parasitic wasps in North America since 1970. One particular group, the genus *Duta*, with three species (parasites on crickets) was common in the early 1970s in many different habitats. At that time, in some areas, up to 50% of eggs of crickets were parasitized by the wasp.

FIGURE 30

Most Canadian forest birds migrate to tropical rainforests such as this one in Nicaragua. Clearcutting in Canadian forests and deforestation in the tropics is causing major declines in neotropical migratory birds *(photo by Ted Mosquin).*

However, Masner reports a steady decline in all three species, and especially in the past five years. Thus, traps operated in 10 locations around Ottawa, Ontario, and representing at least four major ecosystems yielded gradually fewer individuals of *Duta*. A near total crash of populations occurred in 1989/90 (Masner 1991). He reports a similar decline in frequencies, with several cases of possible extirpation, of 48 other species of local scelionid wasps with hosts that develop on or in the soil. Masner attributes these changes to major physical and chemical changes in the soil such as the increased acidity due to aerial pollution. He further notes that in Europe, species of *Duta* and other ground scelionids that occupy the soil niche were already very rare between 1948 and 1968. He suggests that the advanced environmental deterioration in Europe is the likely cause of these trends toward extinction.

Many aquatic insects have much decreased populations or have been extirpated in heavily eutrophic or otherwise polluted water systems. Shadflies include a variety of insects whose larval stage is aquatic, including the mayflies and stoneflies that form much of the basic food sources for many larger aquatic animals and especially fish. The general cause of these major eliminations of populations and species can be attributed to the increasing toxification of both terrestrial and aquatic ecosystems caused by policies of federal and provincial governments, which have allowed the continuing dispersal of herbicides, pesticides, fertilizers, and other chemicals. The chemical industry produces thousands of different kinds of chemical compounds. Over 21,000 tonnes were applied in 1987 in the prairie provinces alone (Environment Canada 1991c). Nearly all these substances are alien to the planetary ecosphere (see section 2.1 for definition). While we see some efforts to regulate use of some chemicals, these are insignificant when considering the scale of the problem (International Joint Commission 1994). With so many negative trends in the incremental toxification of the Earth, the future looks bleak for all life forms except those few whose populations benefit from human activities, can tolerate toxins, or that have the capacity to adapt genetically to the emerging chemical composition in the atmosphere, soils, and waters.

While the overwhelming trends in Canada are toward the continuing loss of species, some species are increasing. These include humans (7.9% increase between 1986 and 1991, a rate almost double that of the previous five-year period), geese of several species, White Pelican, Whooping Crane and White-tailed Deer (especially southern Ontario).

5.6 NATIONAL AND PROVINCIAL PARKS, NATURE RESERVES, AND OTHER PROTECTED AREAS

To determine the degree of success of biodiversity conservation in any nation, one has to know the percentage of its land and water areas that are allocated to achieving this purpose today. While in some nations, the highest level of conservation is no longer possible, even for small areas (because none or only a tiny percentage of the biodiversity remains), this is not the case in large areas of Canada where despite extensive development, industrialization, and large cities, many land and sea areas are still in a relatively natural state. These can still be allocated for this purpose should serious biodiversity conservation become a matter of public policy of governments having the required jurisdiction.

As indicated in Chapters 2 and 3, it is the natural or normal state of any part of the planetary ecosphere that provides the measure of the quality, condition or "state" of biodiversity. We are dealing with the retention of the time-tested norms of the planet as rationalized earlier. Viewed at this geological time scale the most effective biodiversity conservation can be found in protected areas and regions, or areas that are not protected but remain in a natural or near-natural state for a variety of reasons such as remoteness, ruggedness, low natural resource value, or because the area is hazardous to humans for some reason.

Table 8 and Appendix 6 summarize the principal kinds of designations for protected areas in Canada. Appendix 6 also presents Canada's contribution to biodiversity conservation globally by outlining the internationally recognized designations of some of this country's protected sites.

There are 2,872 parks and other protected areas in various jurisdictions corresponding to IUCN categories I to V, encompassing 708,000 km^2 or 7.1% of Canada's land area. Parks and protected areas are not the sole responsibility of the federal government; all provinces, territories, and some municipalities contribute to biodiversity conservation in Canada. The federal government protects the largest area through its national parks, migratory game sanctuaries, and national wildlife areas.

Canada has 34 terrestrial national parks covering about 181,000 km^2 or 1.9% of the country's land and freshwater. These parks range in size from 6 km^2 (St. Lawrence Islands) to 44,807 km^2 (Wood Buffalo). The two underwater national parks (Fathom Five on Lake Huron and the marine part of Pacific Rim National Park) total 285 km^2 in size. There is more freshwater habitat in Canada modified by hydroelectric projects than protected in aquatic parks. The marine component

TABLE 8

TYPES OF PROTECTED AREAS AS OF 1992

Name	Number	Area (km^2)
PARKS		
National Parks	34	180,569
Provincial Parks (non-recreation focus)	682	1,237,300
Provincial Parks (recreation focus)	906	304
ECOLOGICAL[1]		
Ecological Reserves	437	17
Wilderness Areas	38	6,400
Nature Trust Areas	10	7
WILDLIFE		
Migratory Bird Sanctuaries	98	113,127
National Wildlife Areas	45	1,061
Wildlife Management Areas	185	207,548
Wildlife Protection Areas	56	34,298
OTHER		
National Capital Commission	62	521
Conservation Authority	319	547
TOTALS	**2,872**	**1,782,099**

[1] includes Ontario equivalents

FIGURE 31

Freshwater and marine fisheries provide employment for thousands of fishers and fish plant workers, landed catch values (before processing) of $1.5 billion annually. Thousands of Canadian and non-Canadian anglers are drawn to Canada's lakes, streams, and coasts, for recreational purposes and spend an estimate $4.1 billion (the catch and angler values are not comparable as they use different approaches) *(drawing by Charles Douglas from McAllister and Crossman's* Guide to the Freshwater Sport Fishes of Canada*).*

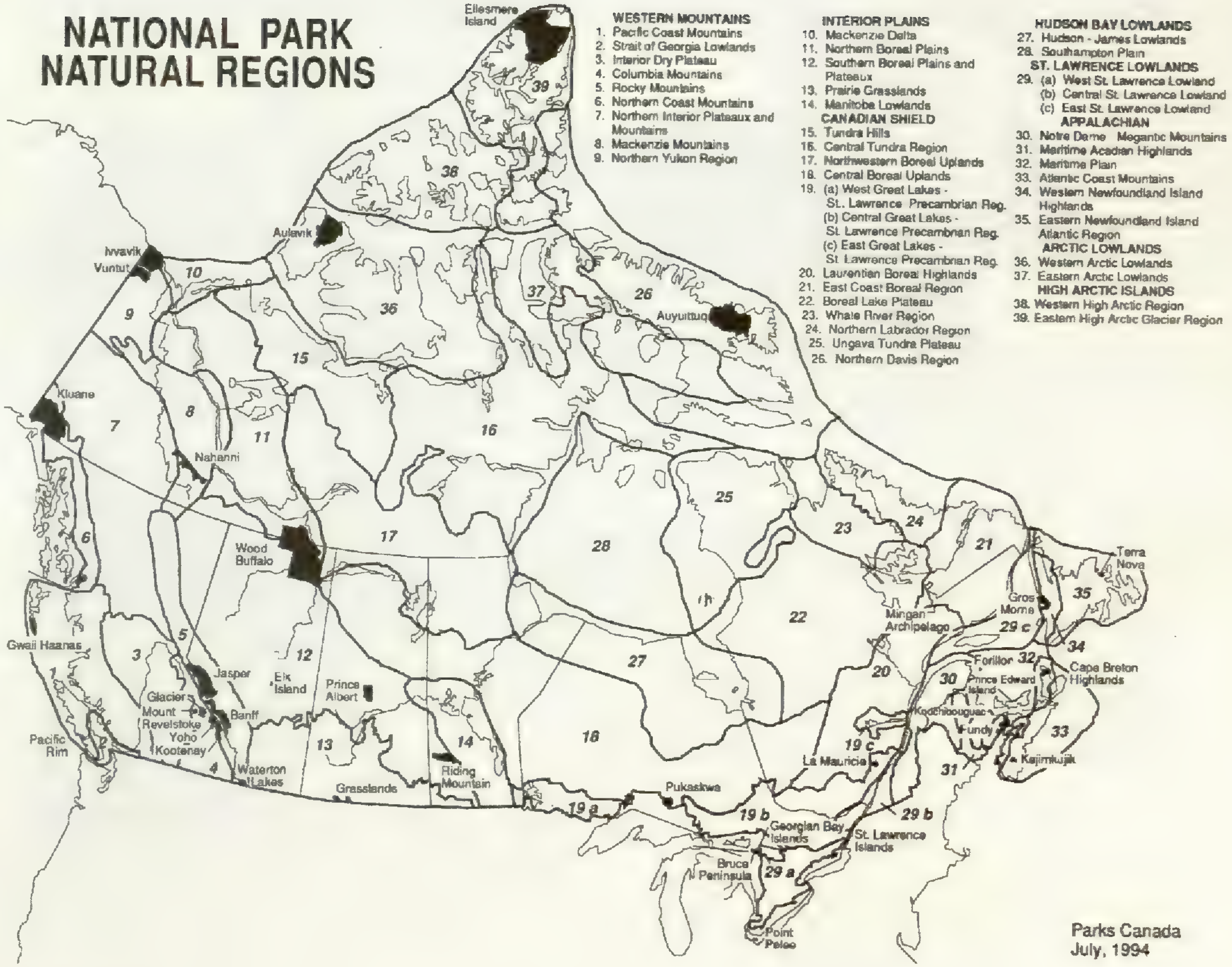
of the Pacific Rim National Park represents less than 0.004% of Canada's 6.5 million km^2 marine area, far below the national target of 12%. National parks form the centrepieces of Canada's protected areas. The objective of national parks is to protect for all time, representative areas of Canadian significance in a system of national parks, and to encourage public understanding, appreciation, and enjoyment of these areas so as to leave them unimpaired for future generations.

National parks fall under IUCN categories I and II and afford a high degree of protection to natural features and for normal biodiversity, although development pressure to commercialize some parks is currently intense, as for example in Banff National Park. Canada's freshwater and marine national parks still permit motorized navigation and commercial fishing. Terrestrial parks prohibit industrial activity (logging, mining) but permit angling in streams and lakes. Most permit recreational activity, camping, and contain modest road networks. Offshore marine areas are not represented in the park system. Offshore "biodiversity reserves" were suggested by McAllister and Gruchy (1977) as an essential method to check on the effects of trawlers and to preserve living examples of total marine faunas. Hunting of waterfowl was recently discontinued in Point Pelee National Park; logging was stopped in 1991 in Wood Buffalo National Park.

It is not yet clear as to whether federal policy will require that the nation's national park staff promote the maintenance of ecological integrity in Canada's national parks as required by amendments to the *National Parks Act* passed by Parliament in 1988. Ecological integrity is not a difficult concept. Chapter 3 outlines the required elements for this idea. That the arrangement of National parks may henceforth place highest priority on the protection of natural ecosystems (rather than on recreation for humans) is suggested by the new policy on national parks (Parks Canada 1994) which places "maintaining ecological integrity and biodiversity of natural areas" as the first priority of management.

The stated goal for acquiring lands and waters for national parks is outlined in the National Parks System Plan (Environment Canada 1990). The goal of the plan is to have at least one national park in each natural region. Currently 21 of 39 terrestrial regions (54%) contain national parks, while only 2 of the 29 marine (one is freshwater) regions (7%) are represented, indicating that protecting natural ecosystems is a low priority of the national government. In the launching of the Green Plan (Government of Canada 1990), the federal government committed to completing the terrestrial national parks system by the year 2000. More specifically, the government's stated goals are 5 additional terrestrial and 2 more marine parks by 1996 (although the sizes are not stated), and agreements for the remaining 13 terrestrial and 3 more marine parks by the year 2000. These goals were supported in a recent report of the Standing Committee on Environment, House of Commons (MacDonald 1993).

Migratory bird sanctuaries (MBS) allocate areas for special protection of migratory birds. MBS regulations forbid a person from carrying firearms in an MBS or trapping any migratory bird. MBSs protect 112,622 km². The Queen Maud Gulf MBS, at greater than 62,000 km², is the largest such sanctuary in Canada. MBSs prohibit the hunting of migratory birds and the harvesting of their eggs or nests as established by regulations under the Migratory Birds Convention. MBSs may include private lands or areas under provincial jurisdiction. However, private land MBSs are no longer encouraged since there is no way of guaranteeing their protection. Several private MBSs have recently been converted into subdivisions. The Canadian Wildlife Service, the federal agency that administers MBSs, has proposed 30 new MBSs over the

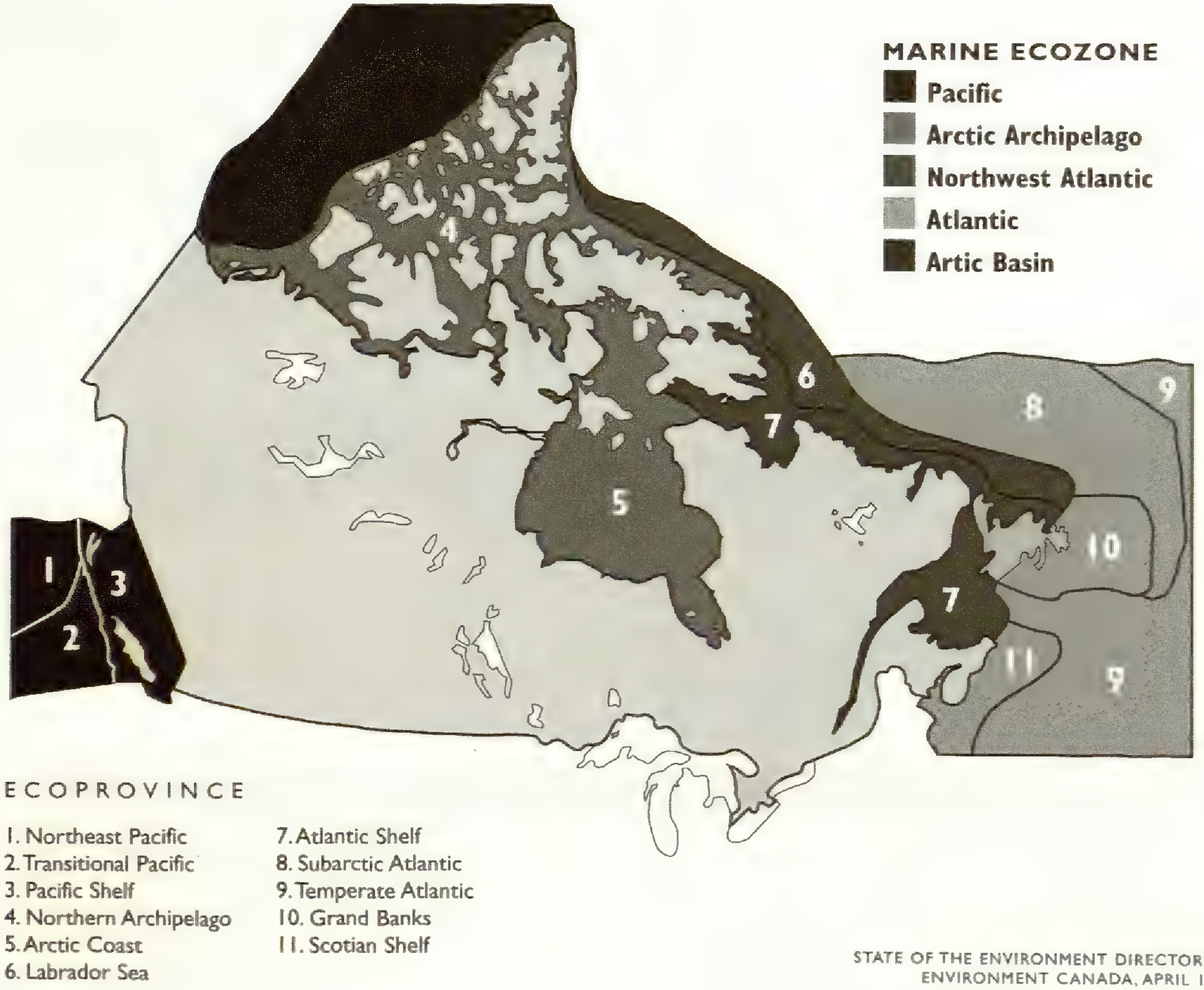

NATIONAL PARK NATURAL REGIONS
WESTERN MOUNTAINS
1. Pacific Coast Mountains
2. Strait of Georgia Lowlands
3. Interior Dry Plateau
4. Columbia Mountains
5. Rocky Mountains
6. Northern Coast Mountains
7. Northern Interior Plateaux and Mountains
8. Mackenzie Mountains
9. Northern Yukon Region
INTERIOR PLAINS
10. Mackenzie Delta
11. Northern Boreal Plains
12. Southern Boreal Plains and Plateaux
13. Prairie Grasslands
14. Manitoba Lowlands
CANADIAN SHIELD
15. Tundra Hills
16. Central Tundra Region
17. Northwestern Boreal Uplands
18. Central Boreal Uplands
19. (a) West Great Lakes - St. Lawrence Precambrian Reg.
(b) Central Great Lakes - St Lawrence Precambrian Reg.
(c) East Great Lakes - St Lawrence Precambrian Reg.
20. Laurentian Boreal Highlands
21. East Coast Boreal Region
22. Boreal Lake Plateau
23. Whale River Region
24. Northern Labrador Region
25. Ungava Tundra Plateau
25. Northern Davis Region
HUDSON BAY LOWLANDS
27. Hudson - James Lowlands
28. Southampton Plain
ST. LAWRENCE LOWLANDS
29. (a) West St. Lawrence Lowland
(b) Central St. Lawrence Lowland
(c) East St. Lawrence Lowland
APPALACHIAN
30. Notre Dame Megantic Mountains
31. Maritime Acadian Highlands
32. Maritime Plain
33. Atlantic Coast Mountains
34. Western Newfoundland Island Highlands
35. Eastern Newfoundland Island Atlantic Region
ARCTIC LOWLANDS
36. Western Arctic Lowlands
37. Eastern Arctic Lowlands
HIGH ARCTIC ISLANDS
38. Western High Arctic Region
39. Eastern High Arctic Glacier Region
Ellesmere Island
Aulavik
Ivvavik
Vuntut
Auyuittuq
Kluane
Nahanni
Wood Buffalo
Gwaii Haanas
Pacific Rim
Glacier
Mount Revelstoke
Yoho
Kootenay
Jasper
Banff
Waterton Lakes
Elk Island
Prince Albert
Grasslands
Riding Mountain
Pukaskwa
Georgian Bay Islands
Bruce Peninsula
Point Pelee
St. Lawrence Islands
La Mauricie
Mingan Archipelago
Forillon
Gros Morne
Terra Nova
Cape Breton Highlands
Prince Edward Island
Kouchibouguac
Fundy
Kejimkujik

Parks Canada
July, 1994

FIGURE 32

National park/terrestrial natural regions. The goal of Parks Canada is to have a national park in each terrestrial ecological region. Of the 39 regions, only 21 have national parks today. Canada's Green Plan commits the federal government to complete the system of National Parks by the year 2000, with 12% of Canada's terrestrial and marine areas protected. The biggest need for national parks is in southern Canada *(Claire Gosson, National Atlas, Energy, Mines and Resources).*

MARINE ECOZONES AND ECOPROVINCES


MARINE ECOZONE
■ Pacific
■ Arctic Archipelago
■ Northwest Atlantic
■ Atlantic
■ Artic Basin
1
2
3
4
5
6
7
7
8
9
9
10
11
ECOPROVINCE
1. Northeast Pacific
2. Transitional Pacific
3. Pacific Shelf
4. Northern Archipelago
5. Arctic Coast
6. Labrador Sea
7. Atlantic Shelf
8. Subarctic Atlantic
9. Temperate Atlantic
10. Grand Banks
11. Scotian Shelf

STATE OF THE ENVIRONMENT DIRECTORATE
ENVIRONMENT CANADA, APRIL 1994

FIGURE 33

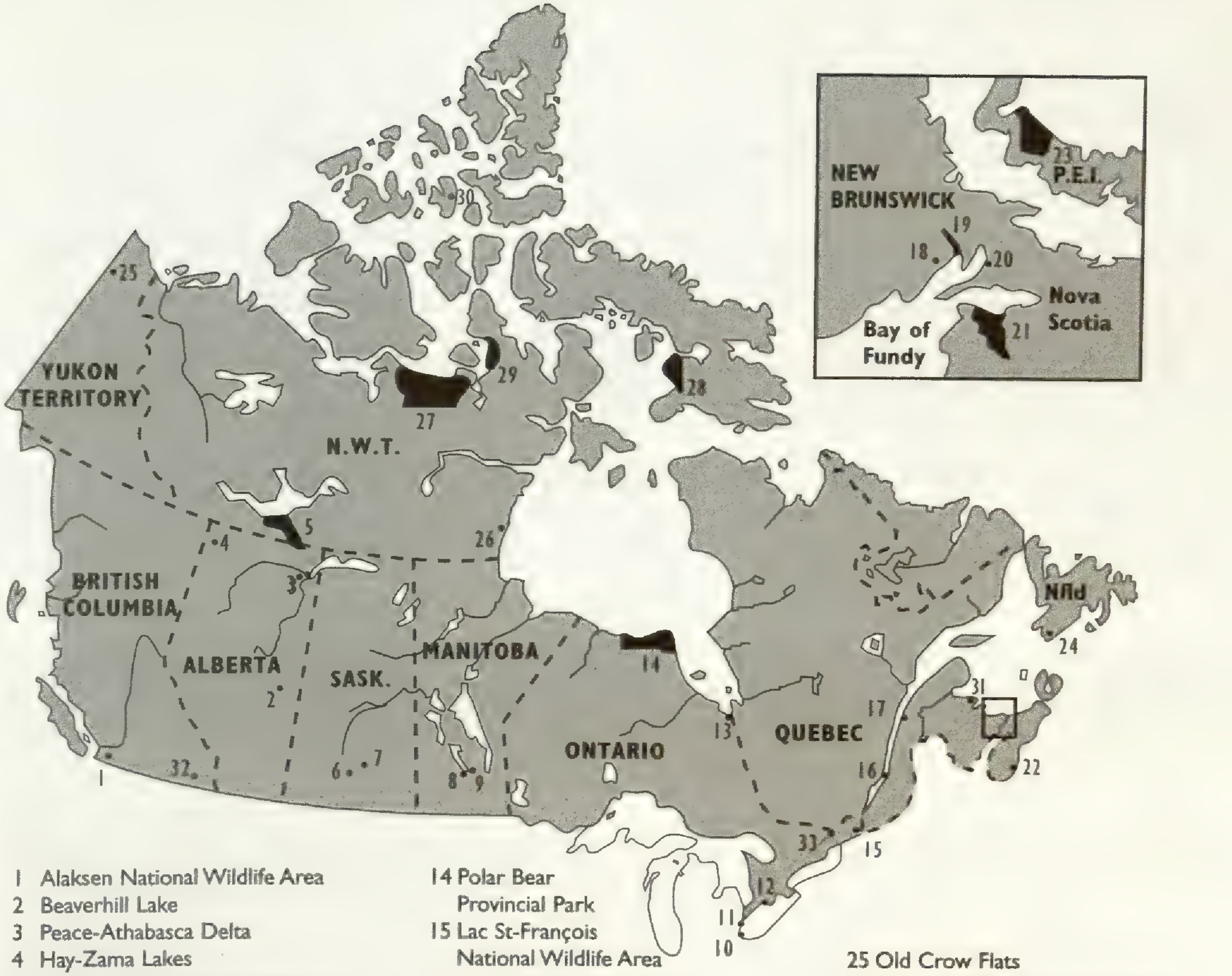
Marine ecozones and ecoprovinces. Of the 29 natural marine regions, only two contain National Parks today.

next six years under Environment Canada's Green Plan proposal, but major cutbacks to the plan have been made. The addition of the 30 new MBSs would add 37,000 km^2 to Canada's areas where migratory birds are protected. All the proposed additions are, however, in the Arctic, where the use of snowmobiles in winter and all-terrain vehicles in summer is an emerging factor in the harvesting of wildlife, which previously had sanctuary through isolation from humans.

There are 45 National Wildlife Areas (NWAs), most of which are in the south and are small in size. The Thelon Game Sanctuary, however, is the second largest protected area in Canada at 55,000 km^2. Together, NWA's protect over 106,000 km^2 of Canada. Originally, National Wildlife Areas (NWA) were established for wildlife research, conservation or interpretation in respect of migratory birds. Today their scope has broadened to include the habitat of all wildlife. Each NWA is managed on an individual basis and may permit limited human interference, including hunting and farming. Also, rehabilitative work is sometimes carried out. Provincial and territorial parks contribute a significant amount of land to Canada's network of protected areas. Together, the ten provinces and two territories protect an area of around 239,000 km^2 or

2.4% of Canada's land area. Traditionally the provinces established parks for recreation. Most provinces license logging in their parks and many permit angling. Today, while recreation remains at the forefront of many parks, biodiversity conservation and the retention of ecological integrity are being considered by park managers as important rationales for parks and protected areas (reasons outlined in Chapters 3 and 4). The provinces and territories have an array of designations to achieve desired levels of protection, including Wilderness Areas, Nature Trust Areas, Ecological Reserves, Wilderness Management Areas, Wildlife Protection Areas, and provincial parks (many of which have their own levels of protection). Here are a few examples:

- Ontario's Wilderness Parks are "substantial areas where the forces of nature are permitted to function freely and where visitors travel by non-mechanized means and experience expansive solitude, challenge and personal integration with nature".
- Nova Scotia's Game Sanctuaries are "established to allow the increase of game species and provide a reserve of game for surrounding forest. Hunting or disturbance of wildlife are prohibited".
- Alberta's Natural Areas are "established to protect sensitive or scenic public



1 Alaksen National Wildlife Area
2 Beaverhill Lake
3 Peace-Athabasca Delta
4 Hay-Zama Lakes
5 Whooping Crane Summer Range
6 Last Mountian Lake Migratory Bird Sanctuary
7 Quill Lakes
8 Delta Marsh
9 Oak Hammock Marsh
10 Point Pelee National Park
11 St. Clair National Wildlife Area
12 Long Point
13 South James Bay Migratory Bird Sanctuaries
14 Polar Bear Provincial Park
15 Lac St-François National Wildlife Area
16 Cap Tourmente National Wildlife Area
17 Baie de L'Isle-Verte National Wildlife Area
18 Mary's Point
19 Shepody Bay
20 Chignecto National Wildlife Area
21 Southern Bight-Minas Basin
22 Musquodoboit Harbour Outer Estuary
23 Malpeque Bay
24 Grand Codroy Estuary
25 Old Crow Flats
26 McConnell River Migratory Bird Sancturay
27 Queen Maud Gulf Migratory Bird Sanctuary
28 Dewey Soper Migratory Bird Sanctuary
29 Rasmussen Lowlands
30 Polar Bear Pass National Wildlife Area
31 Tabusintac Lagoon and River Estuary
32 Creston Valley Wildlife Management Area

FIGURE 34

Canada's Ramsar sites. The Ramsar sites are part of a global network of internationally significant wetlands. Ramsar sites help Canada meet its international obligations to preserve the world's wetland ecosystems and their unique assemblages of species.

TABLE 9

STATUS OF ECOREGION PROTECTION BASED ON AMOUNT OF PROTECTED AREA: IUCN CATEGORIES I TO V (COURTESY: TURNER *ET AL.* [1991])

% Ecoregion Protected (IUCN Categories)	Number of Ecoregions	% of Canada
0	45	16.12
0-1	32	22.62
1-3	20	12.31
3-8	31	23.06
8-12	8	5.07
>12	41	20.80
TOTAL	**177**	**100.00**

land from disturbance and ensure the availability of public land in a natural state for the use by the public for recreation, education or any other purpose".

Together, the provinces and territories protect an area of about 239,000 km². Quebec has allocated the largest area of land; however, only a tiny fraction of the 160,300 km² is devoted primarily to what can be termed as biodiversity conservation with the balance being exploited and fragmented by intensive forestry operations.

Natural ecosystems in six parks have been designated as World Heritage Sites: Nahanni National Park (4,765 km²), Wood Buffalo National Park (44,807 km²), the Canadian Rocky Mountain Parks (20,743 federal + 2,830 provincial = 23,573 km²), Gros Morne National Park (1,805 km²), Dinosaur Provincial Park (7,492 km²), and Kluane National Park (8,500 km²), including its icefields.

Six parks have received Biosphere Reserve status—an international designation. Nine more are considered to be needed (five in the north) for Canada to complete its share of protecting the world's biogeographical provinces, including marine areas.

Canada has 24% of the world's wetlands. Wetlands of international significance, termed Ramsar Sites, of which there are 30 in Canada, encompass 130,000 km²—the largest total area of Ramsar Sites of any country in the world.

It is illegal to hunt in most of Canada's parks. However, poaching for private larders, for illegal sale to the wildlife food market, or slaughter of game for sale of organs such as gall bladders is a concern. Game wardens are unable to adequately patrol against poaching.

5.7 TERRESTRIAL ECOZONES AND MARINE ECOREGIONS PROTECTED UNDER IUCN DESIGNATIONS

Appendix 7 illustrates the present state of biodiversity conservation in Canada by ecosystem. It should be noted that rather than following the UNEP guidelines exactly, we have opted to drop the biotic communities and divide the biogeographic provinces (henceforth called ecoregions) into terrestrial ecoregions and marine regions.

Canada has mapped its ecoregions at different scales. Some ecoregions have protected areas and some do not (Table 9). The strategy and framework for developing a nation- wide system of terrestrial ecoregions for Canada is being developed by the Canadian Council on Ecological Areas (CCEA 1991). The system is based upon a broader range of biophysical criteria than other systems. An ecoregion is an area of the Earth's surface characterized by a distinctive ecological response to climate, physiography, and hydrology as expressed by the development of vegetation, soils, and fauna. The national system (developed jointly by Environment Canada, Canadian forestry Service, Agriculture Canada and all provinces and territories) for a terrestrial classification identifies 15 ecozones, 40 ecoprovinces, 177 ecoregions, and 5,400 ecodistricts. For the purpose of determining adequacy of ecological representation, the ecoregional level is most appropriate for this analysis. Maps are available from Environment Canada, Ottawa.

A similar ecozone and ecoprovince framework has now been developed for Canada's marine areas (Figure 34). This recognizes 11 ecoprovinces and 5 ecozones along Canada's three ocean coasts, a classification obviously less detailed than that for land.

Tables 9 and 10 represent an instructive way of visualizing how much needs to be done to achieve at least representative protection. The analysis has the advantage of being based upon internationally established standards of IUCN.

Table 9 and Appendix 7 show that of the 177 terrestrial ecoregions, 45 have no protected areas at all, while only 1 of the 29 marine regions (one of the "marine" parks is

TABLE 10

DEGREE OF ECOREGION PROTECTION BASED ON AMOUNT OF PROTECTED AREA: IUCN CATEGORIES I AND II (COURTESY: TURNER *ET AL.* [1991])

% Ecoregion Protected (IUCN Categories)	Number of Ecoregions	% of Canada
0	67	32.90
0-1	52	30.61
1-3	19	11.88
3-8	14	13.99
8-12	5	1.95
>12	22	8.68
TOTAL	**177**	**100.00**

in fact in freshwater) contain areas where one should expect to see some evidence of biodiversity conservation. This does mean that 132 ecoregions have one or more areas where biodiversity is better protected (or well protected), but this number says little about representation (or size) within those ecoregions. Canada has 708,000 km^2 (7.1%) of its land and freshwater protected in some form. But less than half of that, only 320,000 km^2 (3.2%) is free from industrial activity or motorized impact. A full 96.8% of Canada is still subject to conversions and impacts to a slight or total degree. These percentages indicate the systemic difficulties, at both the provincial and federal levels, of increasing the land base dedicated to conservation rather than exploitation.

It should be stressed also that each Canadian province has developed or is in the process of developing its own ecological classification for terrestrial and freshwater areas, and that the boundaries frequently do not coincide with the national classification. It is our view that whichever system is chosen within a province or territory, adequate representation of self sustaining ecosystems can be achieved, provided that the level of discrimination (i.e. number of natural regions recognized) is roughly in accord with that of the 177 ecoregions as noted above). Similarly, such marine ecoprovinces should contain at least one large area, rich in biodiversity, protected from exploitation. Some useful documents outlining criteria for selecting ecological areas have been prepared by the Canadian Council on Ecological Areas (CCEA 1989, CCEA 1991; Peterson and Peterson 1991). Copies of provincial ecoregion maps can be requested by writing to appropriate provincial agencies.

5.8 PRIVATE NATURE AND WILDLIFE SANCTUARIES

Appendix 8 outlines the contributions of private sanctuaries to the conservation of Canada's biodiversity. In Canada, federal, provincial, and municipal governments do not encourage private sanctuaries, and any person or group wishing to protect some ecologically valued areas encounters both legal and financial obstacles. One of the most serious obstacles lies in the tax system at municipal and federal levels. Thus private land, which contains quality natural areas (where biodiversity values are high), is generally taxed along with other land designated as "rural," "agricultural," etc. in municipal official plans or zoning bylaws. However, tax rebate programs exist in some provinces for land that contains specific natural values such as wetlands. Ontario has developed a Conservation Lands Tax Rebate Program to assist landowners who will make a written agreement to protect appropriate lands from exploitation or conversion. The rebates are now provided for landowners where provincially significant wetlands or Areas of Natural and Scientific Interest (ANSIs) are found on their properties. Likewise, Revenue Canada discourages and impedes the establishment of private sanctuaries for conservation purposes. It does this by forcing donors to pay deemed capital gains tax on market value of the donated property. Thus, private land held in a family for generations is deemed by Revenue Canada to have been sold at current market prices, even though no money was received by the donor. The deemed capital gain (which can amount to hundreds of thousands of dollars) becomes immediately taxable according to Revenue Canada. Efforts to change this destructive anti-environmental taxation policy in recent years have not been successful.

Notwithstanding the above, some private sanctuaries have been established. Ducks Unlimited Canada (DU) owns and strongly manages the largest number of such sanctuaries. DU is a major participant and funder of the North American Waterfowl Management Plan (1987) whose aim is to produce more waterfowl for hunting, or at least to try to stem the continuing decline of duck populations by providing more habitat for these birds. The bulk of the money comes from the United States, where most ducks are shot. Few other nongovernmental organizations hold really significant sections of lands under their care. The Saskatchewan Natural History Society and the Federation of Ontario Naturalists both own sanctuaries in their respective provinces (Appendix 8). The Nature Conservancy of Canada focusses entirely on acquiring lands that are of major ecological importance, but normally transfers such lands to appropriate government agencies for permanent protection or management.

The idea of private land trusts is currently emerging in Canada as a means through which private individuals would be able to obtain long-term protection for biodiversity on their private property. Trusts have proven to be highly effective in the U.K., New Zealand, and the United States. In the U.S., over 2 million acres have been saved from development through citizens' action backed up by strong legislation (Elfring 1989). In contrast, in Canada, trusts are small and very modest (Reid 1988), and there is strong resistance by governments to provide strong legal framework to reward private individuals for protecting (rather than exploiting) nature on their properties.

5.9 STATUS OF *EX SITU* CONSERVATION FACILITIES

Plants, animals, or micro-organisms are said to be surviving "out of place" or *ex situ* when people have taken them out of their natural ecosystem (where they were evolving on their own terms). Such "captive" organisms are now surviving from year-to-year because of the active care being provided by humans. While in human care, they are also subjected to new selection pressures, including inbreeding, and thus undergo genetic change. Alternatively, when such organisms are able to survive in their native territory on their own terms (as their ancestors did for millions of years), they are said to be growing *in situ*. *Ex situ* conservation facilities include farms, ranches, gardens, private collections, horticultural establishments, botanical gardens, arboreta, natural history museums, experiment stations, seed banks, culture collections, forest plantations and the like. Such facilities also include institutions where records of biodiversity are preserved for scientific study and used in research as for example, dried, pickled, frozen, and otherwise preserved specimens of organisms in every known group (as presented in Appendix 9), to the extent that seeds, pollen, spores, DNA or other genetic materials are recoverable from these specimens. The *ex situ* collections

FIGURE 35

Photos of herbarium sheets in Canadian Museum of Nature. These specimens act as vouchers for computer databases, conservation and resource services, as well as for taxonomic studies that result in popular and scientific guides to Canada's flora *(photo courtesy of* The Ottawa Citizen).

include the majority of phyla from bacteria to large mammals and extensive plant and vertebrate collections.

Appendix 9 lists Canadian institutions harbouring live plants, animals, and microorganisms as well as collections and data bases. Listings of institutions in official directories provided much of the information regarding the number of *ex situ* institutions in Canada. Agriculture Canada staff were contacted for information on seed banks, herbarium and live culture collections. The Plant Gene Resources Program, Agriculture Canada, maintains an extensive and highly valued variety of seed and specialized cultures (Agriculture Canada 1991a, 1991b). A total of 40 zoos, aquariums, and game farms were contacted by fax and/or letter using the directory of zoos, aquariums, and game farms (CAZPA 1991). Some 25 botanical gardens/arboreta were contacted to ascertain their *ex situ* holdings of rare species.

While tabulating the number of the various facilities was relatively straightforward, acquiring a listing of the number of species each held proved difficult. Many of Canada's *ex situ* institutions are unable to provide an accurate list of the number of species that they currently hold in their research departments and staff are reluctant to estimate. It is, however, not difficult to gather information on the number of collections or specimens held in museums, herbaria, or as cultures. This situation is somewhat akin to the state of knowledge with respect to *in situ* conservation facilities such as national parks and natural areas. For the most part, the managers of Canada's natural areas have virtually no knowledge of the microscopic and submicroscopic organisms that occur in abundance or may be very rare in soils and waters of these areas.

For culture collections, the various strains or individual cultures of a species are valued because they are genetically unique. Therefore, for any one facility the number of strains is better known than the number of species. However, an estimate of the number of species was provided by staff of institutions housing these collections.

Zoos, aquaria, and game farms in Canada number about 80, divided among publicly funded and private establishments. The living animals that they keep include both exotics and natives. Many zoos, for example, maintain large collections of snake and primate species as well as the larger, more spectacular mammals, many of which are experiencing difficulty in their native country or range. On the basis of individual groups, the totals are: mammals 200; birds 300; reptiles 50; fish 1,500 and invertebrates 300 species. As would be expected, the larger zoos receive some public funding and keep the largest numbers of species. Prescott (1993) reviews the changing environmental roles of zoological gardens.

A total of 60 botanical gardens, varying greatly in size, contain between 20,000 and 30,000 species. The Jardin botanique de Montréal alone houses 20,000 species of living plants, mainly from other parts of the world. This includes some 130 species of plants that are listed by IUCN as endangered, rare, or vulnerable. This is probably the largest ex situ collection in Canada, although other publicly funded institutions such as the Royal Botanical Gardens at Hamilton are quite large. The Devonian Botanic Garden at Edmonton holds 3,526 cultivars and other selections comprised of 454 different genera, excluding annuals (which would need to be replanted each year). The University of British Columbia Botanical Gardens house 16,000 species and between 200 and 300 of these are considered to be rare, threatened, or endangered. Many other botanical gardens make it a policy to grow some rare or threatened species in collections. However, it is not known whether the plants are ever used for ecosystem restoration work.

Agriculture Canada's Smithfield Experimental Farm in Ontario has become

Canada's clonal repository for horticultural crops. The farm concentrates on preserving clones of fruit crops named by Canadian plant breeders and institutions. Clones of many native horticulturally valuable species are also maintained as a world resource for germplasm. Included are strawberries, raspberries, gooseberries, apples, pears, plums, elderberries, and blueberries. The data on the collections is available on computer diskette.

As for live culture *ex situ* collections of micro-organisms, tissue cultures, animal cells and fungi, a minimum total of 4,000 species are maintained permanently in about 150 institutions across Canada. Holdings are described in detail in the Directory of Canadian Culture Collections (Weldon, Ferguson and Schindler 1986). The two largest holdings are those maintained in the National Collection of Fungus Cultures by Agriculture Canada, Ottawa, and by the microfungus collection and herbarium of the University of Alberta, Edmonton (larger fungi are also stored dried). A total of 21 other institutions maintain nationally important collections. These collections are used for both basic and medical research. Some private companies maintain their own specialized collections related to their commercial operations. For example, one brewery in Montreal maintains the largest yeast collection in North America.

Museums and herbaria house the bulk of dried or preserved specimens of biological diversity, and particularly of the larger organisms. Generally, expertise on different phyla of animal and plant life is available at these institutions. Several invertebrate groups, the lower plants, and micro-organisms are poorly represented in collections. The associated collections data banks contain uniquely valuable data on past and present-day geographical distributions. The three largest holdings of species and specimens are with Agriculture Canada, the Canadian Museum of Nature, Ottawa, and the Royal Ontario Museum, Toronto. Generally, museum staff know the number of collections or specimens. Due to small staffs and/or incomplete computerization of collections, the total number of species in a given collection is often unknown. Therefore, it is was necessary to include in Appendix 9 both the number of species referred to and the total number of specimens. In cases where the total number of species held in institutions across Canada could not be determined by existing data, curators and/or curatorial assistants were invited to estimate the totals.

The world's third-largest museum research collection of insect and arachnid specimens is housed at Agriculture Canada, Ottawa, as is the largest herbarium collection in Canada with 800,000 plant specimens and Canada's largest research collection of macrofungi—some 300,000 specimens. Large collections of macrofungi are also held at the University of Toronto and University of British Columbia. Herbaria and various animal collections are found in all provinces, usually associated with the provincial museum or universities. Quebec currently lacks a natural history museum. In one place or another, almost every "macro" species recorded/known to occur in Canada can be found housed in a museum collection. The largest collections of mosses, lichens, mammals, amphibians, reptiles, fish, crustaceans, and invertebrate groups (other than insects and arachnids) are housed at the Canadian Museum of Nature, Ottawa. A great many of the species housed (in both animal and plant groups) are from other countries. The collections form the core resource upon which biosystematic research work is based. Much of the research into biodiversity could not take place without these collections.

Seed banks in Canada are housed in two principal repositories. The Petawawa Forest Experiment Station maintains a repository of some 240 species of seeds and provenances of forest trees, many from different parts of the world. As well, Agriculture Canada maintains seed banks of 800 species, almost all of which are exotic varieties required in plant breeding. On a much smaller scale, exchanges of seeds and plants occur between different botanical gardens.

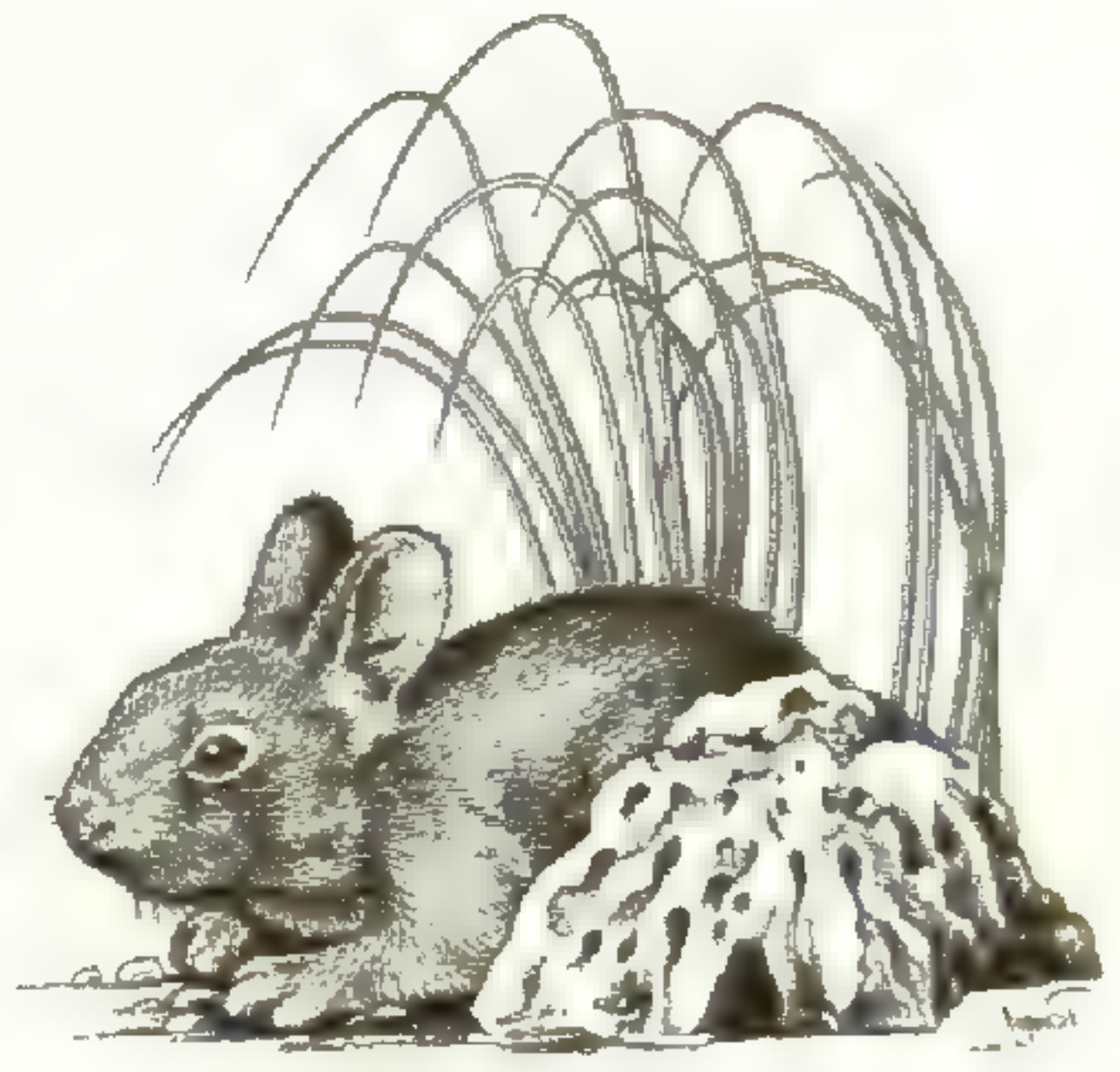
Many of the *ex situ* facilities are in the process of creating computerized databases of their holdings (i.e. museums on the Canadian Heritage Information Network (CHIN) or the botanical gardens association data base), but most databases are incomplete. Therefore, in Appendix 9, the number of species represent a "best estimate" by staff of the various facilities. Data bases tend to focus on specific groups of species, entire collections, or on certain areas of the country. CHIN, Agriculture Canada, the Canadian Museum of Nature (BIODIV), and the Royal Ontario Museum have the country's largest collection of information data banks. Additional details can be secured by consulting the various institutions noted in this appendix.

5.10 ENDANGERED, THREATENED, AND VULNERABLE SPECIES IN NATIONAL *EX SITU* CONSERVATION FACILITIES

Appendix 10 summarizes some of the data that were received on endangered/rare or vulnerable species that are held in the *ex situ* facilities described in sections 5.2.1 and 5.9, and in Appendix 9. Ideally, this Appendix should include all species listed in IUCN red data books, on CITES schedules, or in COSEWIC reports. However, staff of many botanical gardens are unaware of the number of species growing in these gardens and do not know their conservation status. Therefore, the table shows a very incomplete list of native species whose status has been established by COSEWIC and which, on the basis of information received, are known to be now growing or raised in *ex situ* facilities in Canada. Obviously, many exotic rare species of plants are found in Canadian botanical gardens and as house plants, or in private collections, as for example, orchids.

In the botanical gardens of Canada, 11 native plant species are listed as endangered, rare or vulnerable. However, this number represents a minimum estimate as noted above; no doubt many more rare species grow in gardens but are not identified as such. The number of rare or endangered exotic plant species in the gardens has been estimated at 300, but again the actual number could be much higher. For comparison, Argus and Pryer (1990) record 1,009 rare native vascular plants in Canada. At this time no rare or endangered plant species, either native or exotic, is being actively propagated for future reintroduction into the wild.

As for animals, the rare and endangered species now being raised in *ex situ* facilities are listed in column 3 of Appendix 10. The Canadian Wildlife Service has an active *ex situ* breeding and release program for the Swift Fox and the Peregrine Falcon. The aim is to re-establish more wild, naturally reproducing populations. In the past the CWS also had programs for the Bison and Whooping Crane but these have now been suspended due to increased populations. Some Black-footed Ferrets are being raised in the Metro Toronto Zoo for release into natural habitat.



CHAPTER 6

THE ECONOMICS OF CANADA'S BIODIVERSITY

6.1 INTRODUCTION

Canada's diverse biological resources[1] are fundamental to peoples' food, health, work, recreation, culture, and environment. The all-pervasive nature of biological resources and their diversity makes "biodiversity" extremely difficult to value, since in one way or another, virtually all human activity can be related to a dependence on biological resources. Nevertheless, in developing the valuation process and recognizing that many natural values cannot be expressed in monetary terms, this study makes a first attempt at expressing the values of Canada's biodiversity in quantitative and qualitative economic terms.

This economic valuation approach recognizes the distinction between biodiversity and biological resources. Because the concept of valuing "diversity" is new, especially within an ecological functions context, there was not a great deal of material on which to draw. However, there is substantial literature and statistical data on the valuation of biological resources. This latter information was used as the basis for this study. The results presented in this chapter do not purport to represent the value of biological diversity per se. Appendix 13 of this report examines and describes some of the important methodological considerations used in the development of this chapter.

Economic information was viewed by the United Nations Environment Programme (UNEP) as being important to understanding the global dimensions of biodiversity. In defining the approach to be undertaken in the preparation of Country Studies, the UNEP guidelines state that the gathering and presentation of data, both in terms of biodiversity status and economic analysis, will provide a solid basis for the development and implementation of biodiversity conservation and rational use strategies and action plans.

The economics component of this study had several objectives:

1. to derive estimates of benefits associated from Canada's biological resources;
2. to provide an estimate of costs associated with current and proposed measures to conserve biodiversity;
3. to contribute to an overall assessment of Canada's biodiversity and identify gaps

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[1] Biological resources, for the purpose of this part of the report, include all biota of use or potential use to human beings. This definition is non-restrictive and therefore does not exclude any individual species simply because no use (commercial or otherwise) has yet been determined. In this way, biological resources which rely for their existence on non-restrictive species (lower on the food chain) give value to these lower biota. This corresponds with the definition given in the Convention: genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosytems with actual or potential use or value to humanity.

in our methodology or knowledge; and,

4. to comment on the benefits of biodiversity at risk without conservation measures.

This chapter is viewed very much as an initial attempt, and does not purport to be a complete or definitive depiction of the economics of biodiversity or its conservation. However, while previous valuations have been prepared for individual sectors, such as the wildlife study by Filion *et al*. (1993), this is the first study attempting to survey the economics of all of biodiversity. The positive nature and variety of responses which contributed to this report clearly indicate the need for a fuller and more concerted research effort in this area.

In addition, further development of quantitative methods needs to occur concerning the "economics of biodiversity", particularly by international environmental organizations. There is no neat and well established accounting system in economics that recognizes the different values associated with biological resources and biodiversity. Our classification system for biological resources and their use is complicated. The distinction between end product and input is not always clear and therefore the values to be included in a study such as this are not always apparent. Several recommendations in this report suggest partial solutions.

This report begins with some background information on the general approach adopted towards the evaluating biological resources, and follows with empirical results and conclusions. In an effort to ensure its relevance to as wide an audience as possible, this section of the report has been written with a minimum of technical terminology.

6.2 OVERALL APPROACH

The economics component of Canada's Biodiversity was prepared in support a request by the United Nations Environment Programme (UNEP) for national case studies on the status of biodiversity. It is significant that the UNEP guidelines for these studies recognized the need to incorporate economic considerations. This economics chapter was prepared in accordance with the revised guidelines developed by the UNEP International Advisory Team of Experts concerning the preparation of Country Studies (UNEP 1991 amended).

No attempt has been made here to reiterate or duplicate any of the many recent publications on environmental economics. Rather, the approach adopted in this study is to provide a practical example of the estimation of benefits and costs of biological resources and their conservation. Details and points of discussion covering the methods used are contained in Appendix 13.

[2] Among the material available, two are recommended: *Economics of Protected Areas: A New Look at Benefits and Costs*, by John A. Dixon and Paul B. Sherman, Island Press, Washington D.C., 1990; *Economics of the Wilds: Wildlife, Widlands, Diversity and Development,* by Timothy M. Swanson and Edward B. Barbier, Earthscan Publications Ltd., London, 1992.

Those interested in some of the theoretical aspects of environmental economics are directed to any of the volumes currently available on the subject.[2]

6.2.1 BENEFITS CONSIDERED

It is essential to include benefits in the development of national policies and programs for biodiversity. An analysis of benefits helps to indicate the socio-economic values at risk if biodiversity is lost; allows for further analysis of the relative contribution of specific conservation methods; and it can describe the spatial and temporal distribution of these benefits. To examine only the costs associated with biodiversity conservation would provide insufficient rationale for the allocation of funds for conservation alternatives. It is with these primary considerations that this economic study was developed.

Benefits are values derived now and in the future. They are generated through markets where prices represent value, or in non-market situations, where prices or other means are used to indicate value. Non-market values can be measurable in dollar terms, of they can be immeasurable. Benefits can be derived from use as well as from non-use.

The benefits examined in this study include commercial values, expenditure, replacement or imputed values; direct benefit values; and existence and option values. Commercial values are those which are determined by commercial sales or transactions and are generally reported through national statistical organizations. This analysis, has not accounted for the economic impacts associated with these values, or the revenue accruing to governments. Expenditure, replacement and imputed values are derived from a number of different sources based generally on organizational or sectoral lines. These values include such things as hunter expenditures, home consumption values and other calculated values. Direct benefit values are primary benefits received directly by participants in activities (for example, fishing, hunting, touring, etc.). These three broad types of value are the most common sources of monetary value. Option, inheritance and existence values are more difficult to measure and are derived from a

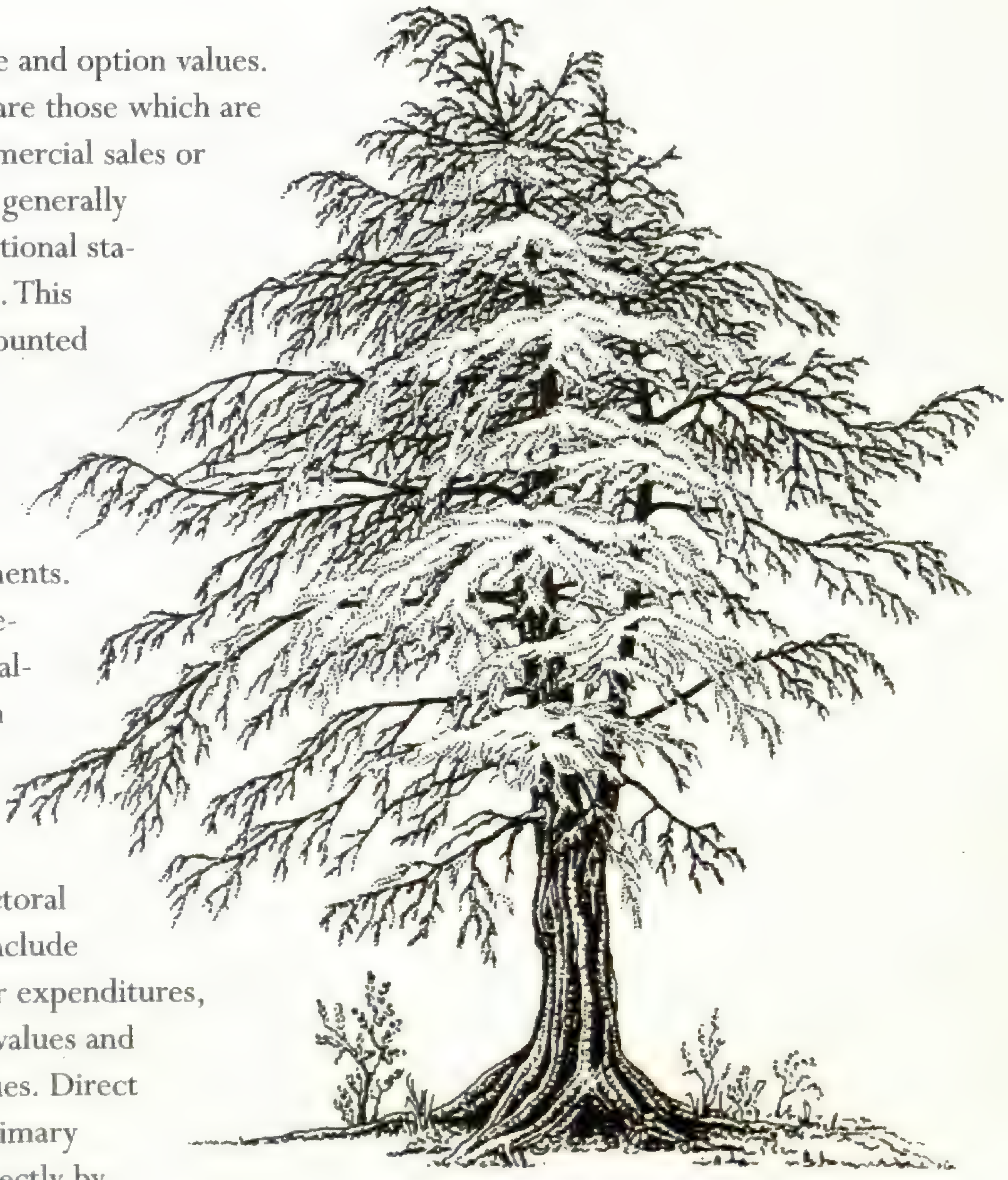

FIGURE 36

The Western yew, long considered a weed species in forest management, produces a chemical that damages cancer of the ovary, breast, and lungs *(drawing by Susan Laurie-Bourque, courtesy of* The Trees of Canada*)*.

variety of sources.[3] In addition to these monetary measures a variety of non-monetary indicators can also be used.

There are other ways in which benefit values could be categorized. For example, expenditure and commercial values could have been amalgamated into one category; however, because of the types of benefits being estimated in later sections of this report, they have been kept separate.

This study attempted to present data that were reasonably comparable and consistent between and within economic sectors. Values that were closest to the resources themselves were sought, so that such measures as farm gate prices, fish landed values, and the value of shipments from saw and planing mills were used for major monetary benefit producing sectors of agriculture, fisheries, and forestry. In other words, no additional values derived from processing, production, or supporting industries are reflected in the figures presented here. In this way value added components to final products were minimized. Equally, cost of production values have not been subtracted from the values used (see Appendix 11). Also, as noted in the methodology (Appendix 13), non-medical drug sales have been excluded from the analysis (although, for example, marijuana production in British Columbia has been valued at up to $750 million annually). The values for other economic sectors were not as easy to classify or obtain, and only some success was achieved in generating comparable and consistent figures. In all cases 1990 information was sought. This was not always possible; the list of references indicates the source of information, including its date.

It is important to note that in following the UNEP Experts' guidelines, the benefits quantified in this study relate to biological *resources*, not biological *diversity*. The value of biological resources is quite different from the value of diversity within and between these resources. Virtually no economic valuation work has been conducted on the values of biological diversity as such. On the other hand, the value of ecological services (see Table 2 and Chapter 4) was estimated relatively: low, medium and high in accordance with the guidelines.

6.2.2 COSTS CONSIDERED

Cost figures for the conservation of Canada's biological resources used in this report are derived in several ways. For the most part these are incurred by various levels of government, nongovernmental organizations (NGOs), and public and private companies. Costs examined by this study concentrate on those incurred by governments and NGOs. All financial cost types are included (operations and maintenance, capital, grants, transfers, etc.). Similar to benefits, these costs provide a "snapshot" of one year (1990).

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[3] Option values relate to future use (may not be occurring, but the opportunity for future use is valued); e.g. the taxol found in the Western Yew, as described in Section 6.2. Existence value is not related to use: a value is assigned for subjective reasons separate from any aspects of actual use; e.g. the well being associated with the knowledge that particular species exist.

Several areas important to the analysis, but not examined in any detail, are the "disbenefits" of maintaining biodiversity (for example, health problems caused by biological resources); the opportunity costs[4] associated with conservation activities, the social and other external costs associated with benefit production, and the opportunity costs of factor inputs. Presenting only the positive side of biodiversity conservation ignores the fact that there is also a negative aspect that must be acknowledged. The latter two cost areas are important to consider but go beyond the ability of this study to address adequately.

6.2.3 SUMMARY

To facilitate use of the figures gained through this study, the report examines separately the benefits of Canada's biological resources and the costs of maintaining Canada's biodiversity. No inference should be made that these results reflect a benefit-cost analysis. The benefits and costs derived in this study are neither complete nor comparable.

6.3 SIGNIFICANT RESULTS

The results of the data collection process represent a compilation of benefit and cost figures that were either obtained from published sources, or provided by individuals and organizations. A worksheet of annual benefits resulting from the use or existence of biodiversity was used to accumulate annual benefit figures. These completed worksheets are contained in Appendix 11. Cost information is also presented in worksheets in Appendix 12. Significant results are presented below. It is recommended that readers examine both of these Appendices for an appreciation of the breadth and mix of information collected.

6.3.1 BENEFITS DERIVED FROM BIOLOGICAL RESOURCES

The quantification in economic terms of the benefits associated with biological resources and biodiversity is difficult to achieve. As described in Appendix 13, there are a number of conceptual and practical problems to overcome. One of the overall problems is the absence of a consistent single view of what constitutes benefits, or how to classify these values (primary, secondary, direct, indirect, net, gross, etc.). Whereas there is general agreement in the established commercial sectors, conventions that cover

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[4] Opportunity costs indicate the lost value associated with not allocating resources to the next best alternative. i.e. the cost of what was given up.

FIGURE 37

Pollen grain microphoto. Pollen, carried by wind, insect or other pollinators, enables enrichment of genetic variation in plants, enhancing their capacity to combine advantageous inherited characteristics and to adapt to changing environments *(photo by Dr. David Jarzen).*

such values in non-commercial areas have not been universally adopted. Significant variations in the definition of these terms are still apparent. As a general rule, therefore, the monetized values presented in the worksheets are not strictly additive. However, summaries of the values in the four categories (commercial value; expenditure, replacement, imputed value; direct benefits value; and existence or optional value) have been made where possible, to give a sense of the orders of magnitude of these values.

For reporting purposes, benefits have been grouped into plants, animals, micro-organisms and ecosystems. The economic benefits of plants are estimated first.

6.3.1.1 PLANTS

Plants generate economic values in a great many ways: food, medicine, clothing, shelter, habitat, ecosystem functions, and in other less tangible ways. Not surprisingly, these values add up to extremely significant amounts (see Appendix 11 for a detailed listing of species and values used to generate the figures presented here).

Plants and plant products from agriculture generate large monetary values in Canada. In 1990 some of these values (farm cash receipts) were as follows ($Canadian):

grains	*$ 6,574,482,000.*
legumes	*399,551,000.*
animal feed	*5,718,400,000.*
vegetables	*517,104,000.*
fruits	*319,504,000.*

Nationally and globally, agriculture displaces and reduces much of wild biodiversity, but compensates to the extent that new crop forms and races of higher economic value are developed and maintained. However, in a vast majority of situations, crop production entails a single crop or monoculture, usually with deliberate efforts made to reduce the incidence of negative interaction with other biological agents through the application of pesticides and herbicides. Because of these impacts, and because agricultural landscapes often represent a of natural and modified mosaic, it is by no means clear the extent that agricultural crop production affects overall biodiversity or that it represents a true net economic value. Rather, these kinds of production values point to the *potential values* that could be generated by other plant species when (and if) production possibilities are recognized and acted upon. The extent to which other such opportunities exist for our plant species decreases as we reduce the diversity of plant species through out agricultural and other practices.

While sizable values are documented for commercial agricultural crop production, there is virtually no information on the value of home production. It has not been possible to estimate comprehensively the value of home production for either agricultural products or forest resources (construction material and fuelwood), although indications suggest that this value would be substantial. For example, the estimated annual value of fuelwood, lumber and round logs in the Northwest Territories is $5 million. Other areas of Canada would generate significantly higher values.

Reliable information was available, however, on the value of forest wood-fibre production. The value of lumber and wood by-products represents a real biodiversity value (approximately $ 7.5 billion annually). Wood is harvested almost exclusively from natural stands as most tree plantations have not matured to a harvestable level. Plantations represent about 3% of the forest fibre benefit value (i.e. approximately $225 million annually).

Canada's forests have a pervasive ecological and economic importance. Values are generated from fibre, fuelwood, wildlife, recreation, water quality, and other crops (such as blueberries, flowers, etc.). In addition, the shade provided helps reduce the harmful health effects of ultraviolet radiation. Only limited dollar values are available to report on these many sources of benefits.

No data for several categories of plant use that would indicate real biodiversity values were available. Little information was uncovered relating to the subsistence value of wild plants whether used for food or medicinal purposes. There were few figures available on the value of aquatic plants and only hypothetical figures on the values of plant-sourced compounds or chemicals used in pharmaceuticals. As well, aquatic and upland plants feed waterfowl, and pharmaceuticals have significant dollar value in human and livestock disease treatment and prevention. These uses of biological resources should have large economic values.

There is little information on the economic value of marine plants, both as an environment and as part of the food chain (although all fin and shell fish fisheries rely on both larger seaweeds and microscopic life forms at the base of the large food chains).

Based on the quantitative results (see Appendix 11), conservative estimates of the values derived annually from Canadian plant

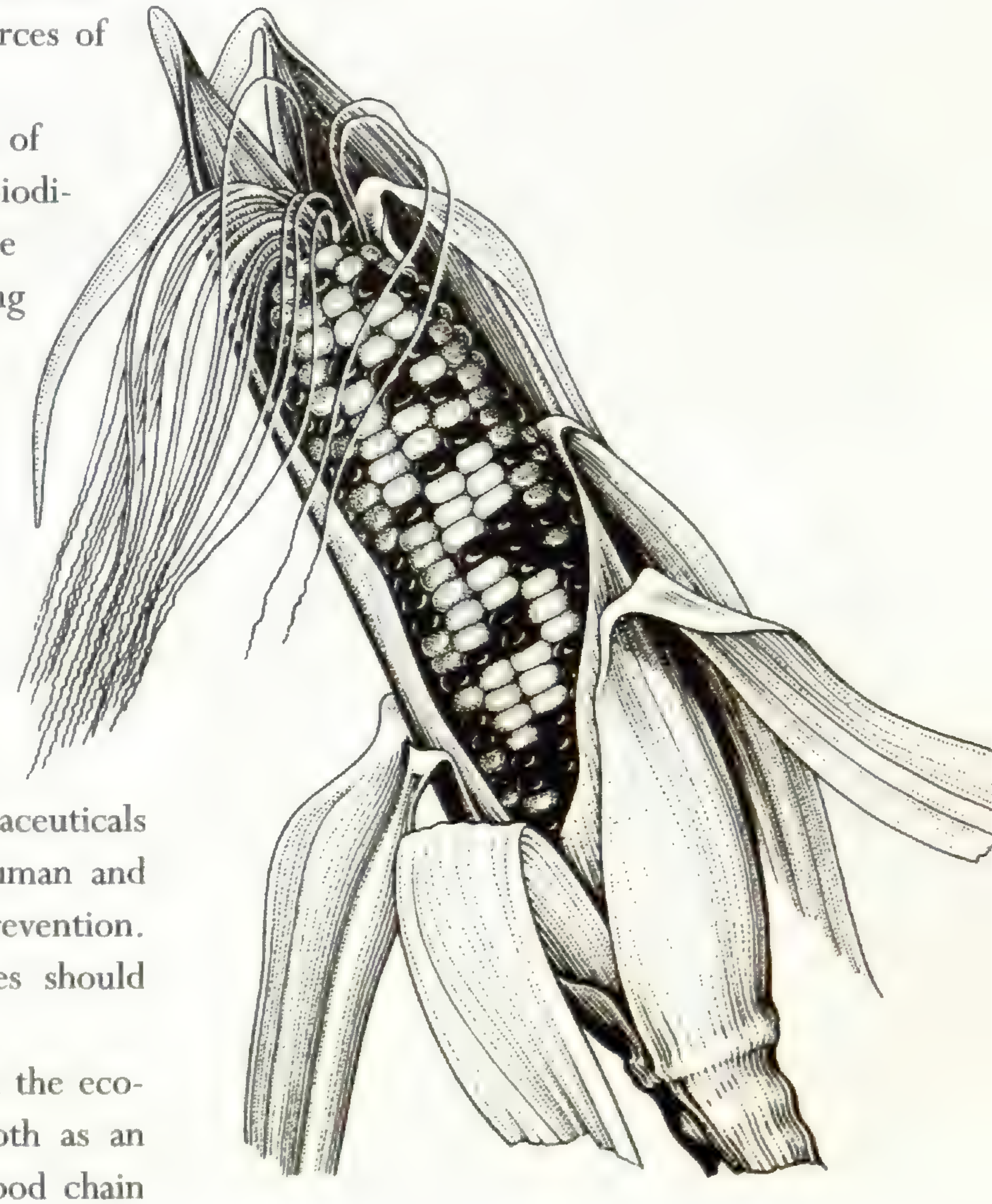

FIGURE 38

Maize, one of the many crops developed from natural biodiversity by indigenous peoples *(by Roelof Idema, courtesy of* Global biodiversity*)*.

resources in the four categories of benefits are:

Commercial value:	*$ 18 billion*[5]
Expenditure/ replacement/ imputed:	*$ 10 billion*[6]
Direct benefit:	*not available*
Existence/ optional value:	*not available*

6.3.1.2 ANIMALS

Animals also have significant value — whether domesticated or wild. Similar to plants, the full economic value of animals is not well established. Appendix 11 presents the details, listing the values related to animals derived from this study and summarized below.

Trapping, hunting, and non-consumptive activities reflect a real value derived from a diversity of biological resources; they involve wild native animals almost exclusively. A large proportion of the trapping benefits accrue to aboriginal communities. This contributes to the continuation of an established way of life and an historically sustainable use of resources. About half ($30 million) of the actual fur market, however, is supplied by fur farms, i.e. fur-bearing animals raised in captivity. The export value of trapped furs, according to some sources, has averaged $100 million per year in recent years.

Fish catch values provide another real biological resource value: the catch, excluding aquaculture (valued at over $48 million), is not cultivated. An increase in the harvest attributable to aquaculture, if conducted in an environmentally friendly manner, may promote the diversity of naturally occurring fish populations and protect their habitats in the future. The total landed value of catches is approximately $1.5 billion annually. The recent crash in Atlantic fisheries (some 20,000 persons directly affected) demonstrates the economic importance of taking seriously the ecologically sustainable management of this resource.

Cultivated animals such as farm livestock have immense economic value in Canada ($11.3 billion). However, livestock can contribute to a decrease in biodiversity and a change in plant and animal communities found in the agricultural use area, soil erosion, and compaction. In counting the value of both livestock and livestock feed, some double-counting is inevitable; the value of the livestock feed is inherent in the value attributed to the livestock.

Only limited information was uncovered on the subsistence value of animals. The harvest of mammals, birds, and fish by both native and non-native groups is substantial, and conceivably has a large real value. Recent estimates of this domestic economic value in the Northwest Territories stand at between $50 million and $75 million annually. The harvesting of animals for home consumption in all provinces and territories would add considerably to the annual total. There is no reliable information on the illegal trade in wildlife parts such as black bear gall bladders, antlers, etc., but it is known that many bears and ungulates across Canada are being poached.

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[5] This figure is considered a good indication of commercial raw material value.

[6] This figure is considered a low estimate of this total value.

Recreational wildlife values indicate that animals have a substantial economic value in several different sectors, and provide income through service industries to regions currently lacking the range of income generators found in urban areas. Nationally, wildlife benefits are estimated at $6.1 billion annually. This amount is based on approximately $5.1 billion of expenditures and $1.0 billion of direct benefits. The total benefit from recreational fisheries is estimated at $4.1 billion annually.[7] Angler surveys have also indicated that the natural environment experience is as important, if not more important than catching fish.

There are few results which indicate the option, inheritance and/or existence values that can be attached to the social, cultural,

FIGURE 39

Canada's coastline is the longest of any country in the world. A number of economically important marine species, such as cod and tuna, are migratory. Canada should institute protected areas on its offshore fishing banks and in international waters to protect biodiversity and act as controls on impacts of industrial fishing gear *(photo by Don McAllister)*.

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[7] It should be noted that the value generated by the recreational fishery is in no way comparable with the value presented for the commercial fishery. Totally different approaches are used in the derivation of the two values and each represents different sources of value.

and symbolic importance of animals in Canada. There are some results that are more exploratory in their nature, being small area and/or species specific, rather than national in scope or significance. Recent projections by the Canadian Wildlife Service indicate these values range between about $276 million and $1.1 billion per annum.

Crude and minimal estimates of the annual values associated with Canada's animals are:

Commercial value:	*$ 3 billion*[8]
Expenditure/ replacement/ imputed:	*$ 11 billion*[9]
Direct benefit:	*$ 1 billion*[10]
Existence/ optional value:	*$ 276 million to* *$ 1.1 billion*[11]

6.3.1.3 MICRO-ORGANISMS

In spite of the fact that life as we know it would not be possible without micro-organisms, it is nevertheless very difficult to affix a realistic and representative dollar value to them. Their ecological and economic importance is undeniable. For example, yeasts used in production of bread and alcoholic beverages for example are beneficial in an animal's digestive system, useful as agents of decomposition or in partnerships in lichens, and they enable the recycling of nutrients essential to the growth of trees, crops, and fisheries (Section 5.1.2). As such, many micro-organisms contribute to the production processes of other goods, and thereby, in economic terms, have values that have been incorporated into the production of these other goods.

Still, values may be applied to the uses for micro-organisms. Fungi (such as penicillium and sulpha), bacteria, and viruses are very important in the food (cheese and yogurt, for example) and medical industries (vaccines or drugs), although it has been impossible to locate specific information on the value of these micro-organisms for this study. Many pharmaceuticals such as antibiotics, and organic acids such as citric acid are produced industrially from fungal cultures.

Notwithstanding the lack of benefits studies, the industrial value and importance of micro-organisms are manifest in their varied use in medicine, agriculture, forestry, and industry and research. For instance, some bacteria are used intentionally or function naturally in the clean up of oil spills and the plugging of oil reservoirs. BT, *Bacillus thuringiensis*, which kills butterflies, moths, and skippers, is important as a replacement for wide-spectrum chemical pesticides. Its use decreases the need for chemical pesticides with their high ecological impacts and

[8] This figure is considered a reasonable estimate of this value.

[9] This figure is considered a reasonable estimate of this value.

[10] This value is considered a low estimate.

[11] This value is considered low.

adds value to the trees relieved of spruce budworm or gypsy moth infestations (although still impacting other neutral or beneficial lepidopterids). Increasing numbers of insects are being used to control crop pests, and other undesirable exotic species and plant alkaloids and fungi show promise in target-specific control of pests in biological controls.

6.3.1.4 ECOSYSTEM VALUES

Ecosystem values relate to the benefits realized from plants, animals, and micro-organisms within a defined area or region. The recreational value of ecosystems in Canada is very high, even excluding any estimate of their option and existence values. There is obvious value to flood control, water purification, nutrient cycling, soil formation and protection from erosion, although these benefits have been difficult to quantify.

National and provincial parks with nature sanctuary zoning (as opposed to recreational and historical parks) are examples of ecosystem units. The value associated with these units is generated through the primary benefits received by visitors, the expenditures of visitors to visit them, the educational benefits received by visitors, and the benefits received by non-visitors through optional demand or their inheritance and existence value. Conservative calculations of benefits produced by Canada's National Parks in 1984-1985 included an estimate of attributable visitor expenditures of $308 million. A more realistic figure for 1990 is approximately $600 million. Socio-economic information on Provincial and Territorial Parks is incomplete.

While their value for maintaining ecosystem processes is not, for the most part, easily estimable, some of the quantifiable values obtained on Provincial Parks include the following:

NEW BRUNSWICK

$293 million spent by visitors on trips to Provincial Parks

ONTARIO

Approximately $7 million received in revenue from Natural Environment and Wilderness Parks

SASKATCHEWAN

Approximately $6 million in revenue and visitor's consumer surplus an estimated $25 million

BRITISH COLUMBIA

Approximately $3.8 million in revenue

There are many other types of ecosystems at the sub-provincial and territorial level. These include municipal parks, land reserves, conservation areas, forestry areas, and other government managed areas. In addition,

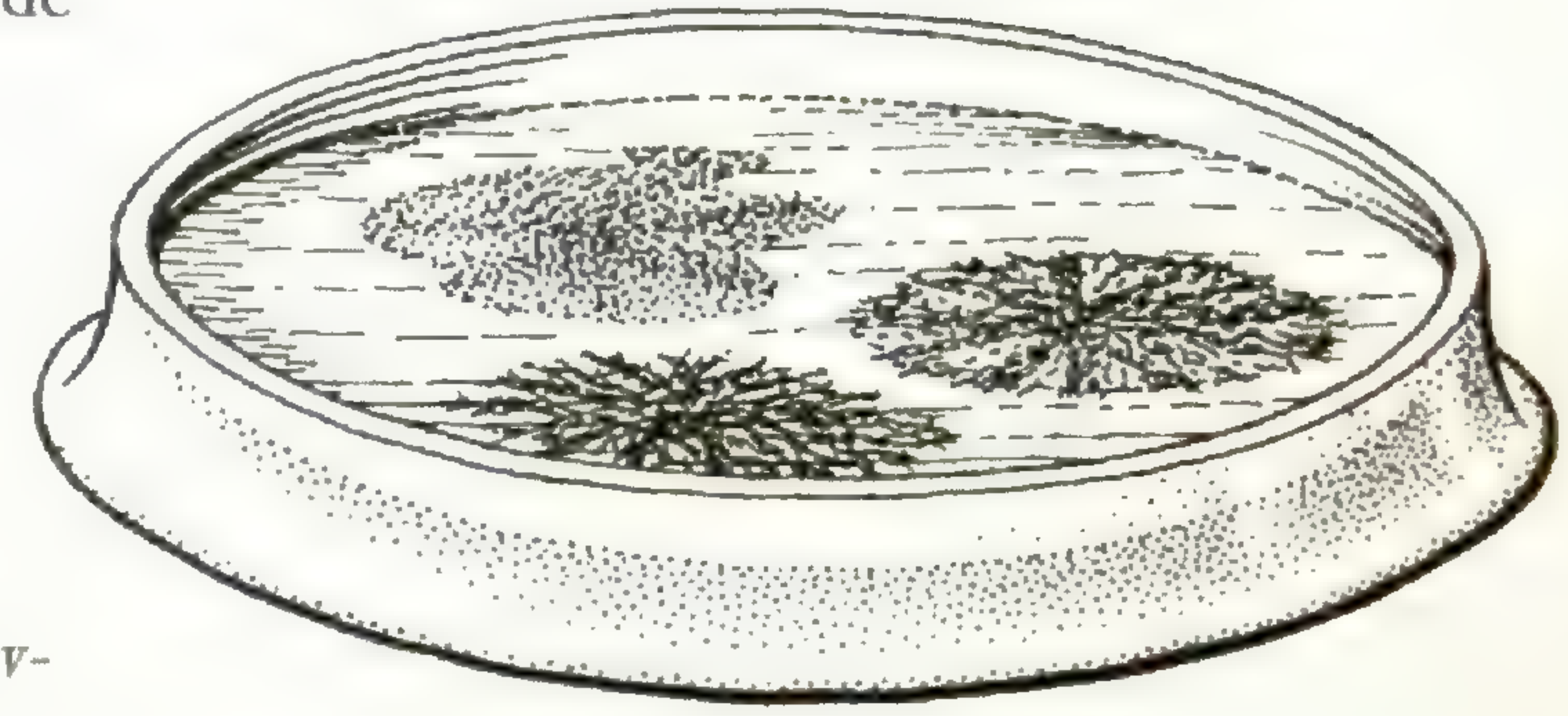

FIGURE 40

Agar dish with micro-organism culture. Fungi-like yeasts and antibiotics are the bases of huge industries in baking (bread), alcoholic beverages and antibiotics. The fungi in healthy soils promote the growth of plants through recycling and transmission of nutrients. Yet wild fungi are poorly known taxonomically and ecologically. New knowledge would offer better conservation, resource management and provide support for the new bioindustries *(drawing by Roelof Idema)*.

FIGURE 41

Recreational use of Canada's parks and other protected areas is on the increase, leading to the continuing losses of species such as large carnivores, which require isolation from large numbers of people. About 20 million visits per year are recorded for Canada's national parks *(photo by Ted Mosquin).*

many private landowners manage and maintain their holdings (or parts of their holdings) for the many inherent ecosystem values, as well as their own private recreational pursuits. While there have been some studies of government-managed areas, few are of an economic nature. No research was available on the private and public benefits from conservation practices on private land holdings.

Other ecosystem elements included in the estimation of economic benefits were various types of institutions'museums, herbaria, aquaria, universities, and others. While the estimation of benefits from these types of ecosystems is difficult, revenues and other socio-economic indicators do provide an overall indication. Unfortunately, much of this information from specific institutions is incomplete. Nonetheless, the benefits worksheets contained in Appendix 11 do provide an indication of substantial activity and value. For example, the Kortwright Centre for Conservation provided public education for 110,000 people and had revenues of over $400,000; the Royal Ontario Museum attracted over 950,000 visitors; and the Manitoba Museum of Man and Nature had revenues of almost $870,000.

While eco-tourism is a promising new area of interest, it is still in its early stages of definition. As yet, there does not appear to be a consensus about what should be included in its consideration, and therefore included in its attributable values. Two provinces (New Brunswick and Ontario) offered some examples of the types of activities that exemplified their definitions of eco-tourism: tour operators taking people to view Atlantic Right Whales; a tour to see puffins; visitors watching the sandpiper migration; hiking tours along the Fundy Coast; birdwatching; wilderness mountain biking tours. To date, because of definitional problems, only crude estimates of the values of eco-tourism have been made. For the most part these values have already been included in the wildlife and recreation-related uses of biological resources described earlier.

Although the values of agricultural produce (plant and animal) are described in earlier sections, organic farming, or the practice of farming in such a way as to create ecosystems that achieve naturally sustainable productivity, should be noted here as an economic activity that is growing in popularity for both producers and consumers. A growing proportion of agricultural production available to consumers is thus being grown using 'organic' practices. For example, according to Canadian Organic Growers, 11% of farms in Quebec have converted to organic methods.

Because of the incomplete nature of the results obtained for ecosystems, it is not possible to provide complete values for the four categories presented in the first two sections. However, the *incomplete* values (underestimates) obtained are:

Commercial value:	*$ 557 million*
Expenditure / replacement / imputed:	*$ 13 billion*
Direct benefit:	*$ 172 million*
Existence / optional value:	*not available*

6.3.1.5 SUMMARY OF BENEFITS

Most of the benefits derived from biological resources are received by Canadians. A summary of benefits derived from biological resources considered in this study is presented on the following four pages. The quantified benefits described illustrate only part of the benefits picture: many unquantified benefits exist that do not appear in these figures, and there are significant levels of benefit largely omitted from the analysis in the form of ecosystem functions or services (Chapter 4), optional use, inheritance and existence values. No available values are indicated by 'n/a' in these tables.

Although this report has concentrated on close-to-resource values, it has been suggested that it may also be useful to briefly describe the ultimate importance to humans of some of these resource values. For example, the value of food sales in Canada in 1988 was over $41 billion, of which meat, fish, and poultry accounted for almost $9 billion; fruits and vegetables for over $5 billion; and dairy products almost $5 billion. In the case of forest resources, the value of cut wood increases 844% to $49 billion in industry shipments. Forest harvesting provides direct and indirect employment for approximately 888,000 people in Canada. At a more specific commodity level, sales of tobacco products in Canada in 1988 generated revenues of $3.8 billion, of which $2.5 billion (66%) went to governments. Canadian tobacco producers received approximately $262 million. Clearly, biological resources are important to both the private and public sectors of Canada's economy.

Data from the Summary Table is presented graphically in this figure. The large values associated with plants and animals relative to the smaller quantified values of micro-organisms and ecosystems. It is interesting to speculate that in addition to summarizing the dollar benefits derived from plants, animals, micro-organisms, and ecosystems, this graph also illustrates the predominant areas of our knowledge on how biological resources generate value. It is not so much, for example that micro-organisms

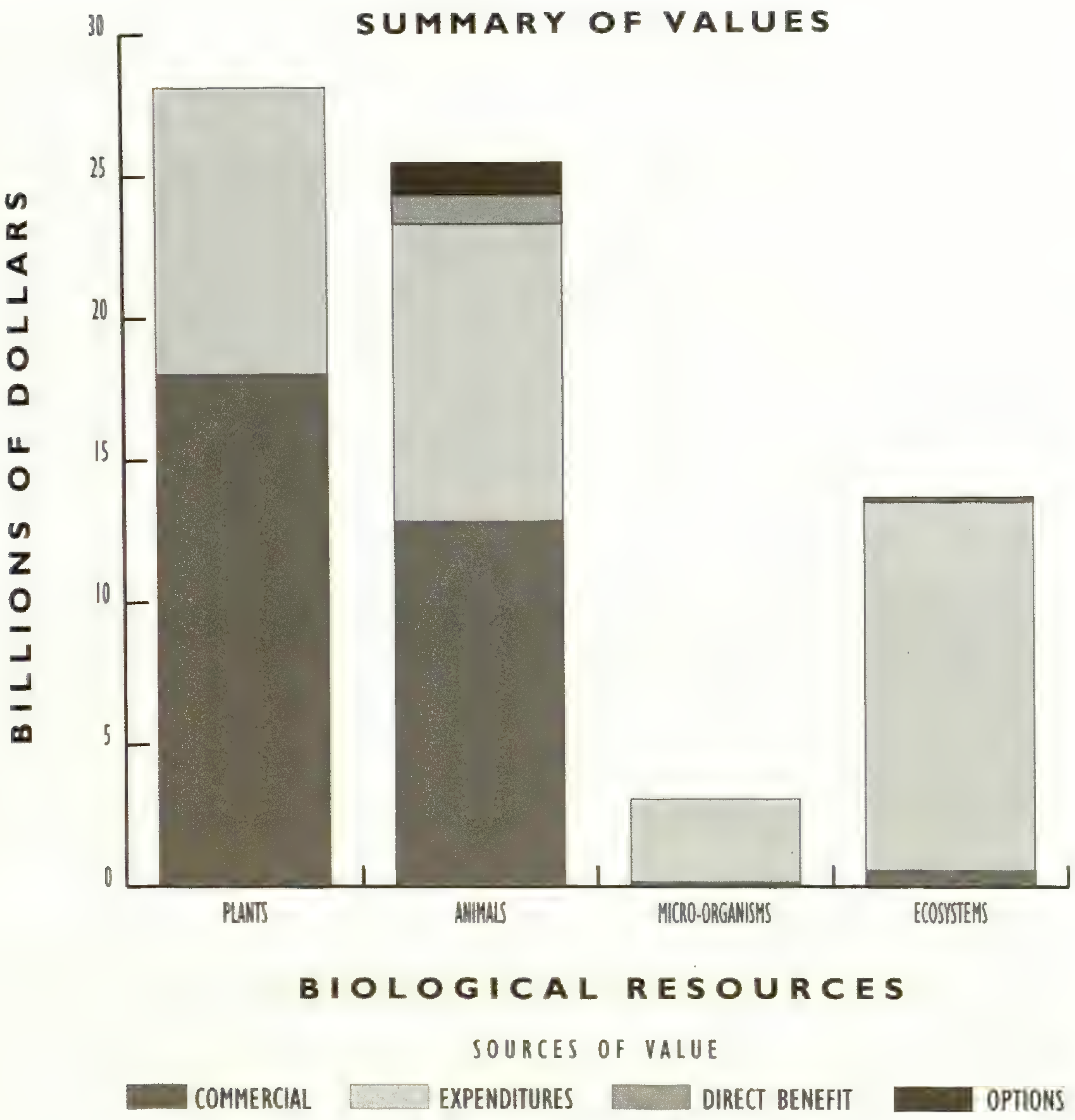

FIGURE 42

Data from the Summary Table is presented graphically in this figure. The large values associated with plants and animals relative to the smaller quantified values for micro-organisms and ecosystems. It is interesting to speculate that in addition to ecosystems, this graph also illustrates the predominant areas of our knowledge on how biological resources generate value. It is not so much, for example, that micro-organisms generate little value, it is perhaps more that we do not understand them fully, and therefore, do not know how to quantify their (biological and economic) values in quantitative terms.

generate little value, it is perhaps more that we do not fully understand them, and therefore, do not know how to quantify their biological and economic values.

6.3.2 COSTS OF CURRENT CONSERVATION MEASURES

Whereas the original UNEP Country Study guideline (UNEP 1991) annexes requested conservation costs associated with specific sites and species, most cost information is not organized in a corresponding fashion. Most cost information is categorized on an agency or organization basis. As such, the expenditures of these agencies on matters related to their fields of concentration or expertise can be likened in a generic way to sites and species, but only rarely to any specific species or site. Most of the agencies incurring costs could not provide cost information in this format; consequently, the analysis of costs is primarily on an institution or agency basis. Appendix 12 provides detailed information on costs.

Public, private, and nongovernmental organizations spend considerable amounts on the conservation of biological resources as well as on activities directly related to biodiversity: education; interpretation; research; resource management, etc. The information collected is not complete, especially for private and nongovernmental organizations, but even the limited material gathered so far presents some impressive results. Based on research into public sources of information and the responses received from the requests sent across the country, Table 11 provides a summary of relevant figures for responding private organizations and NGOs (which include museums, herbaria, aquaria, nature centres and zoological institutions, and some environmental organizations).

Responses from the various post-secondary institutions offering instruction in biology and related fields and/or research into biology and biodiversity conservation yielded varying amounts of data. The universities do not store information in a standardized format, and so their responses did not always correspond with the requested areas. Although the figures are not always comparable, Table 12 presents budget information and the per student expenditure from the several Canadian universities which provided figures in response to the request for information. It should be noted that some universities adopted a fairly restricted view of their teaching and research activities related to this subject, while others interpreted biodiversity in its broadest sense.

Part of the research effort in this study went into the identification of costs incurred

TABLE 11

SUMMARY OF COSTS INCURRED BY RESPONDING PRIVATE ORGANIZATIONS AND NGOS IN THE CONSERVATION AND PRESENTATION OF BIOLOGICAL RESOURCES

Type of Institution	Number of Institutions	Total Annual Budgets ($)
zoos	29	61,408,000
aquariums	4	18,385,000
museums	9	18,054,000
nature centres	7	2,896,000
herbaria	3	1,186,000
environmental organizations	8	68,876,000
Total	60	170,805,000
Overall average per institution		$2.8 million

NOTE: It would be somewhat misleading to separate the costs incurred by governments in conserving biodiversity from those of many other institutions when in fact, government is a major source of funds for many of these organizations. All levels of government (federal, provincial/territorial and municipal) contribute directly to many of the conservation efforts and activities carried out by many of the nongovernmental institutions included in the above figures.

TABLE 12

EXPENDITURES BY RESPONDING UNIVERSITIES ON BIOLOGICAL AND RELATED EDUCATION AND RESEARCH

University	Budget Figures Given ($)	Cost per Student ($)
University of Victoria	1,564,000	4,500
University of British Columbia	1,700,000	3,000-5,000
Simon Fraser University	500,000	n/a
University of Manitoba	25,2791,99	n/a
University of Windsor	3,052,500	5,500 (c)
University of Guelph	80,000,000	22,850 (c)
University of Toronto	n/a	11,967
McGill University	55,000,000	8,540 (c)
Université du Québec á Montréal	10,007,700	n/a
Université du Québec á Chicoutimi	1,527,500	11,068
University of New Brunswick	3,484,300	7,660
Université de Moncton	1,180,000	8,550
Technical University of Nova Scotia	856,500	n/a
Memorial University of Newfoundland	11,436,000	4,115 (c)
Total	19,587,700	

NOTE: These budget figures are not comparable with each other: some include salaries and some do not. Each includes different departmental budgets. (c) = calculated by the consultant.

by the federal government, which is involved in many activities directly and indirectly related to biodiversity throughout the country. At this stage of research, the information for specific federal departments presented in the worksheets should be viewed as estimates only. There are problems associated with separating the implications of programs identifying multiple objectives of which biodiversity conservation may be an indirect or peripheral one (Appendix 13 describes the problems in some detail).

While the figures need considerable refinement, preliminary estimates of expenditures related to the conservation, and research and/or management of wild and cultivated biological resources are as follows ($):

National Research Council	*75,281,000*
Natural Science and Engineering Research Council	*140,000,000*
Engineering Research Council	*140,000,000*
Fisheries and Oceans Canada	*367,771,000*
Forestry Canada	*531,414,300*
Indian and Northern Affairs	*38,570,000*
Agriculture Canada	*201,931,600*

IBPGR Plant Genetic Research	*500,600*
Environment Canada	*526,190,000*
Energy, Mines and Resources	*885,000*
Health and Welfare Canada	*1,812,300*
National Defence	*380,000*
Industry, Science and Technology	*14,334,000*
Medical Research Council	*41,514,000*
International Development Research Council	*938,400*
Western Economic Diversification Canada	*25,000,000*
Canadian Museum of Nature	*11,093,000*
TOTAL	***1,977,615,200***

These expenditures total just under $2 billion, which suggests that no more than this amount is being spent by the federal government on activities related to biodiversity conservation. Expenditures by provincial governments would increase this overall amount substantially. For example, eight of the provinces and territories spent a total of approximately $70 million on natural parks, and seven of the provinces and territories spent a total of approximately $121 million on fish and wildlife management. The province of Quebec, whose figures are not included in the foregoing, spent almost $232 million on Fish and Wildlife, and Parks. These totals do not include all provinces and territories, nor all their expenditures on biodiversity conservation activities.

While not explicitly distinguished in this report, no differentiation has been made between activities directed at conservation of natural areas or species and those aimed at correcting past mistakes. The former implies a proactive planning perspective: the realization, a priori, that certain areas/species need to be conserved. The latter activities are remedial and indicate that past actions did not recognize the value of particular areas/species. In future analyses it might be useful to make such distinctions.

Another area of expenditure analysis that requires further research and consideration is the cost incurred by private (for profit) organizations in conserving species and ecosystems. These costs are often incurred for legislative/regulatory reasons or to fulfil corporate public relations and responsibilities. Examples of such private expenditures were provided by the Province of New Brunswick, with the following list of activities that private companies undertake toward conservation and interpretation in that province:

- contribution of land to Ducks Unlimited for wetland habitat enhancement;
- 200 foot buffer strips along/around waterways and water bodies;
- woodland for elementary school;
- undisturbed archaeological sites; hiking/snowmobile trails allowed;
- recreational parks, boy scout camps, tenting/picnic sites;
- fish restocking contributions;
- adjustment of forest harvest techniques such as partial harvest;creation of nature areas, plus intention to reserve more such sites;
- other efforts to support natural area identification;
- development of campsites, boat launch ramps, nature trails and picnic areas;
- freehold areas open to public;
- support for University of New Brunswick forestry students: forestry camp;
- garbage collection projects at fishing spots;
- work with New Brunswick Hunters Association identifying landmarks to keep hunters from getting lost;
- maintaining and encouraging a dialogue between company and area residents;
- promoting and supporting research efforts towards timber management and wildlife populations;
- plantings of new trees each year.

These activities represent real costs, but in several cases the decision to preclude some uses, such as allocating lands for natural areas, can lead to extremely high opportunity costs. As described earlier, these costs are associated with non-use and can be measured in terms of income, jobs, and revenues foregone.

Another example of the co-operative approach occurs in Nova Scotia where the Maritime Fishermen's Union and the federal Department of Fisheries and Oceans contribute to the collection of ship trash in an effort to alleviate fish habitat degradation from refuse which otherwise might have been thrown overboard, and to lessen the number of "ghost" nets and traps left uselessly, ensnaring fish and whales on the ocean floor, or debris that occupies habitat.

Other more major costs frequently overlooked are the mitigative activities of companies and public organizations for such things as re-routing pipelines, hydro wires, roadways, etc. around environmentally sensitive areas. These expenditures add considerably to the costs of undertaking such developments. The amount of these costs is frequently ignored in the assessment of conservation related costs, and has not been estimated here.

Certain segments of the renewable resource commercial production sectors are implementing production and harvesting strategies which are more "natural" (less use of pesticides, herbicides, etc.) and finding a market for their "natural produce." This involves a drop in productivity, possibly an increase in the cost of production, and eventually a higher price for the consumer willing to pay for this more natural product. The full costs associated with major sectoral changes that result in increased "natural" production are immense, but have not been estimated here. Equally, nor have the out-of-sector future benefits (better fish and wildlife production and human health), which must also be of immense (and greater) value. Notwithstanding, the costs to Canadian producers of non-conversion to environmentally friendly processes and products may be high — loss of competitiveness in domestic and international markets. Likewise, the failure in the past to naturally regenerate or replant logged areas of forests can be seen as a loss to the forest industry.

6.321 SUMMARY OF COSTS

The preceding section sheds some information on the costs being incurred by private and public organizations related to the conservation of biodiversity in some way. The following provides a brief summary of these costs associated with the conservation of biodiversity and/or biological resources.

Non-Monetized Costs: additional costs to private and public organizations to conserve biodiversity; opportunity costs associated with conservation expenditures and lost efficiencies; provincial and municipal government expenditures on biodiversity conservation; individual landowners conservation activities costs; other associated costs.

Institution	Estimated Expenditures ('000s)
RESPONDING Zoos, Museums, Aquariums, Herbaria and other Environmental Organizations	$ 160,096
RESPONDING Universities	$ 195,558
RESPONDING Provincial Agencies (Parks, Fish & Wildlife, Other)	$ 549,176
Federal Agencies	$ 1,977,615
Total Monetary Costs	$ 2,882,445

6.3.3 OVERALL RESULTS AND BENEFITS AT RISK

Because of the sparse amount of quantitative information and the limited time, it is difficult to conduct any real overall analysis of the benefits and costs related to the conservation of Canada's biodiversity. Some aspects remain unsatisfactory: comparisons of the figures obtained are not always possible; standard definitions are not universally adopted; and the lack of a framework for an acceptable method of assessing benefits and costs derived from biological resources are all major barriers. Nevertheless, certain points can be made and comments can be provided on the benefits at risk if conservation efforts are not undertaken.

Enormous dollar value benefits (crudely estimated at approximately $70 billion annually) are derived from biological resources throughout Canada, and large unquantified benefits have been identified as stemming from biological resources. The substantial values generated reinforces the necessity of conserving these resources: their wide diversity adds further to their overall value. It is evident that some of these benefits may be at risk if current conservation measures are not continued and new methods of conservation are not developed and implemented.

In spite of the fact that the measures are partial and incomplete, it is apparent that the costs expended on activities related to the research, management and conservation of biological resources are also substantial. Figures presented here amount to approximately $2.9 billion annually.

The distribution of benefits and costs related to the conservation of biodiversity has not been dealt with in any great detail in this report. All the same, it must be recognized that this is a fundamental issue related to the conservation of biological diversity: the questions of who reaps the benefits and who bears the costs are integral.[12] Canadians' sense of equity requires that those who obtain the benefits should also be prepared to shoulder the costs associated with the production of these benefits (e.g. polluter pays principle). Public policy and the administrative framework of resource use have a large role to play in this question of distribution. Important questions of jurisdiction and policy frameworks have largely been ignored in this report.

There is another aspect to the distribution of benefits and costs associated with biological resources that concerns the historical way in which accounting for natural resource activity is accomplished. At the national level, no recognition is given to changes in the stock of natural (including biological) resources. This means that, for example, as forests are harvested, no recognition that the stock of Canadian forest resources, and all their associated values, has also been reduced. In current national accounting terms, the clearcutting and sale of forests would be viewed as a benefit only. The fishery example, mentioned earlier, is another illustration of the problem. The current system of national accounts shows depletion of the cod fishing stock over the last decade, for example, as a benefit to Canada. No recognition of the costs (now being paid) were included in the national accounts. While not obvious from the figures presented in earlier sections, the way in which Canada accounts for its natural resources needs to be changed to reduce such distortions and more closely reflect the benefits and costs of managing these biological resources. This matter is addressed in the recommendations (Chapter 7).

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[12] A current example concerns fisheries resources on the Grand Banks: Canadian fisheries quotas have been significantly cut back, costing the Canadian fishing industry about $200 million annualy and the loss of about 9,000 jobs, while other nations continue to harvest amounts which are considered to be non-sustainable. (*The Globe and Mail,* Canada Moves to Save Fisheries, January 6, 1992.)

Multiple uses of resources, especially forests, generate benefits in a variety of different ways. Forests are important for their fibre value, but they are also important as habitat for wildlife, natural vegetative crops, recreation and species and ecosystem studies, water quality, fisheries resources, hydro-power generation, and eco-tourism, as well as the maintenance of ecological functions (Chapter 4). When viewed in this broad manner, the timber/fibre value of forests can be seen to form only one part of the total value generated. This clearly has significant implications for the management of these resources, and the derivation of maximum benefits over the long term.

There is a risk associated with a loss in diversity. Most of the benefits that can be monetized with reasonable ease are derived from economic sectors which are not, or do not, appear to be adversely affected by concerns about biological diversity, viz. vulnerable species are not common in commercial agriculture, fisheries or forestry. The areas where resources are at risk are those where there is little or no current commercial use or rationale for sustained use, because there is no "value" associated with them. It was with this in mind that the analysis of the economics of biological resources in this section of the report deliberately examined non-monetizable values of *all* biota, meaning the sum total of biodiversity (with ecological functions or services) and including biological resources. Therefore, those areas/species under stress and suffering the greatest threat to their sustained existence create the most substantial challenge for economic evaluation. It is imperative to include these areas/species in the decision-making processes that will affect them. Further work is required in a number of areas to ensure proper evaluation of such areas/species, or on a case-by-case basis.

Most of the monetized benefits derived from Canada's biological resources, which amount to several tens of billions of dollars annually, are not at risk from human impact upon natural systems. Commercial production monetized benefits will vary according to market prices for the commodities and/or from government income/assistance policies. Future benefits from commercial production of biological resources that have yet to be identified could be at risk if the diversity of biological resources is not conserved. The extent of such commercial benefits is clearly unknown.

Many of the values generated from expenditures, replacement calculations, and imputations are at risk from lost biodiversity or other environmental threats. These values amount to billions of dollars annually in Canada and indicate the importance of home production/consumption, subsistence use of wildlife and fisheries, and other basic biological resources for tourism and outdoor recreation.

The sizable values derived from direct benefits, while of necessity incompletely reported in this report, indicate the level of widespread concern for the maintenance of biological resources. These values would be at some risk if biodiversity conservation activities were not effective.

Existence, inheritance, and option values generated by biological resources and biodiversity are only partially known in Canada. The figures used in this study indicate large values but the effect on them from a loss of biodiversity is difficult to project. Doubtless, they would be severely impacted by significant losses of biodiversity.

There is no way of determining the proportion of benefits that may be at risk if biodiversity conservation measures are not undertaken. All that can be surmised is that uncertainty about future needs and conditions indicate the need to err on the side of caution, since, ultimately, human life depends upon the ecosystem functions that the monetary and non-monetized benefits described above encompass.

CHAPTER 7

CONCLUSIONS, OPTIONS AND UNMET NEEDS

This report's findings, conclusions, suggested options for action, and estimates of future needs have been developed in response to a major new factor on the world stage: the United Nations Convention on Biological Diversity. The convention is unique; it concerns itself with the status, values, and survival of all living organisms and ecosystems, whether or not they have natural resource value today. It also concerns itself with the sustainable use of biological resources, and relations between nations on these matters. Hence, the convention is all-encompassing and promises to be an important key to the future survival of biodiversity and to governing many aspects of international relations.

The Convention, if successfully implemented, would affect hundreds of bilateral agreements. It would also affect many other international conventions and agreements that cover the management and zoning of public and private lands, the internal use of a nation's biological resources, and trade in all such resources. International agreements that give environmental issues a lesser priority than trade should be rethought and drafted. It is important to follow and participate in the actions of nations attempting to carry out the articles of the Convention, and to monitor the activities of countries avoiding their responsibilities to the Convention. This report's conclusions, discussion of options, and estimates of future needs contributes to this end.

Canada is now systematically developing a national strategy to implement the articles of the Convention at home and in our dealings with other nations. This task is being led and coordinated by the Biodiversity Convention Office (BCO) of Environment Canada. A draft national strategy was released for public discussion in June 1994 as part of an effort to seek input from as many Canadian individuals as possible. A final document designed to set a direction for Canada to implement the Convention is now completed and available from the BCO. At the same time, some provinces, notably British Columbia and Quebec have initiated plans to develop their own biodiversity conservation strategies, based on the final national strategy document, which deal more specifically with matters in the Convention that fall under provincial jurisdiction.

Throughout this report, we have drawn numerous specific conclusions about the value, condition, and state of biological diversity and biological resources. There are, however, some general conclusions presented in this final chapter. These concern the state of our national information and knowledge base, suggestions for research and conservation, and a vision for the longer term.

7.1 BIOLOGICAL INFORMATION AND KNOWLEDGE

It makes sense that the conservation and sustainable use of a nation's biodiversity should be based on an objective understanding of the state or condition of the different parts of biodiversity, as well as assessments of qualitative and quantitative trends in the different components or parts of our biodiversity. This section examines the state of our information and knowledge.

7.1.1 MEASURING THE STATE OF GENES, SPECIES, AND ECOSYSTEMS

There is a rising recognition of the need for better knowledge of genes, species and other taxa, ecosystems, and the functions of organisms and processes in ecosystems. As has been described in this report, there are large gaps in our knowledge of Canadian biodiversity, particularly of micro-organisms and of functions and processes of organisms and ecosystems.

A significant lack of information on biodiversity at the genetic level means that studies of genetic variation and adaptations in the roughly 70,000 known Canadian species are few and far between. Conclusions drawn here concerning the probable presence and importance of "genetic level" biodiversity are mostly inferred from the literature on population biology. However, examples of firmer knowledge are presented in this report. The genetics of a tiny fraction of 1% of Canada's species has been studied using one or another of the techniques outlined in section 3.1. This major gap in knowledge of genetically based variation in species is evident from reading review papers such as that by Barrett and Kohn (1990). The implications of lack of knowledge of genetic diversity are important, for example, in the designation of areas where populations, species, and entire ecosystems should be protected *in situ*, as well as in the choice of organisms which should be protected *ex situ*. This gap was identified in a workshop held October 28-29, 1991, and published with recommendations (Stevenson and Fraleigh 1992).

About half of Canada's estimated 140,000 non-viral species have been described by science. The unknown half are mainly micro-organisms. Canada's larger species has been described, and at least something is known about their occurrence and functions in ecosystems. Appendix 1 reveals the gaps in taxonomic knowledge. As one example, a recent paper (Behan-Pelltier and Bisset 1992) notes that for soil arthropods alone (mites, spiders, crustaceans, insects, etc.) soils are both species-rich and phylogenetically diverse. The authors note that of the roughly 48,500 arthropods expected to occur in North American soils, about 53% have been described. As well, keys to the identification are available for only 51% of known fauna, and data on feeding habits exist for an estimated 10%. This kind of information demonstrates the intimate relationship that must exist between systematics and ecology. This situation provides one clear-cut example of the need to have a good taxonomic knowledge base that can be applied to soil conservation, sustainable resource use, and related issues or problems. As in other ecosystems, keystone species of various types must surely exist in different kinds of soils.

Only scattered research has been carried out on the ecological functions of organisms or the workings of whole ecosystems, but there is an emerging literature (summarized in Schultze and Mooney 1993) in these areas.

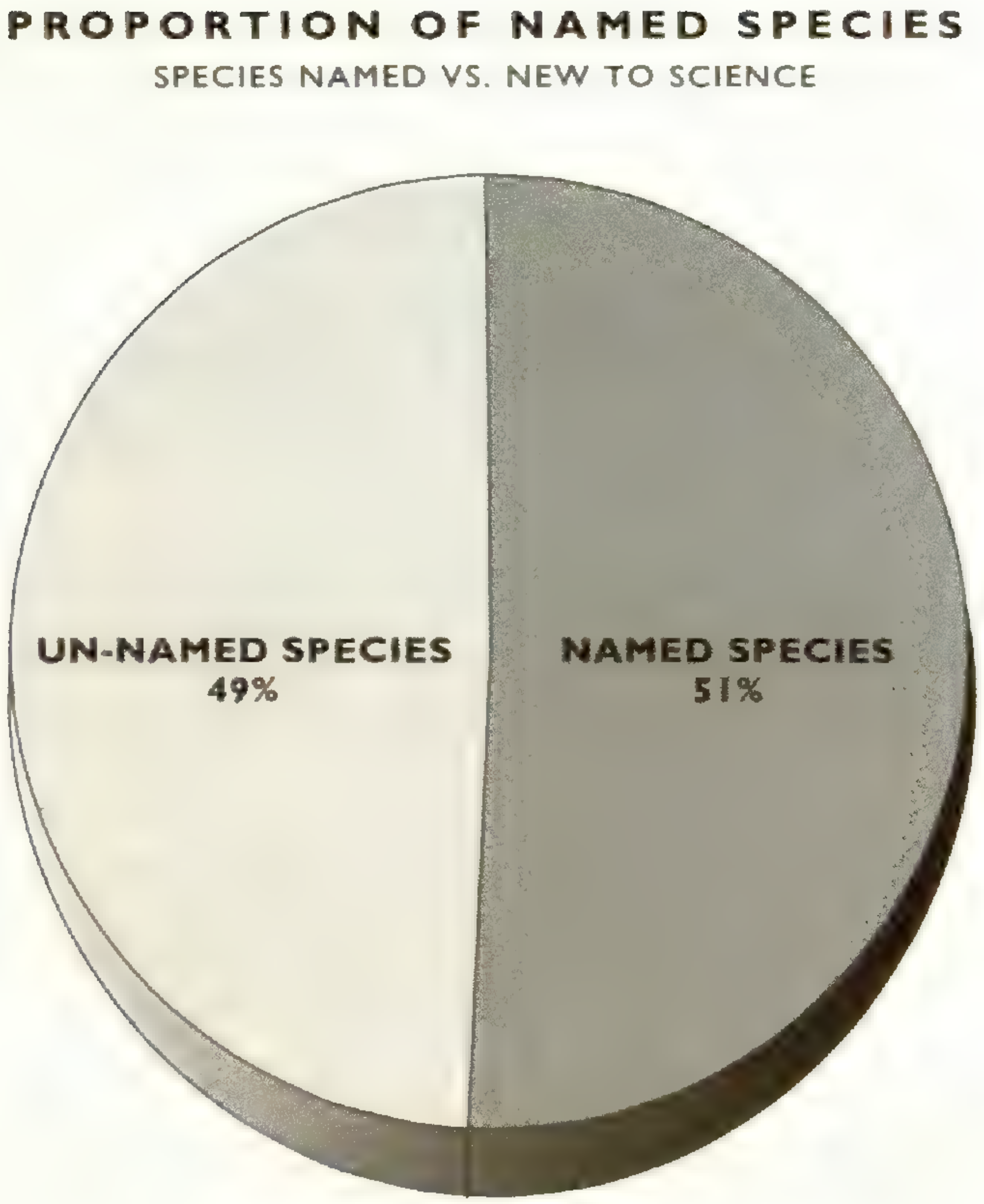

FIGURE 43
Pie chart showing the proportions of non-viral organisms in Canada which are scientifically described and those that are yet to be discovered and named or recorded. This graph shows that taxonomic work on our biota is as yet only half completed (*graph by Don McAllister*).

Functions and processes describe what organisms do for the environment in which we all live. In the past, most of the values of wild species and natural ecosystems were centred around the notion of "wise use", implying that the greatest values of resource species were to serve the human enterprise. Today, with the planetary environment in difficulty in many regions, species and ecosystems are increasingly valued for their so-called ecological functions or ecoservices to other organisms, to ecosystems, and to the health of the lands and waters. Hence, the functions organisms perform naturally for each other and for the health of the ecosphere as a whole are being examined (for example, Schneider and Boston 1991; Solbrig 1991; Grassle *et al.* 1992; Mosquin and Whiting 1992).

From this perspective, what we know about the functional significance of biodiversity to life on Earth and to humanity's future is merely rudimentary, fragmentary, and superficial. Low societal valuation of what genes, species, natural ecosystems, and ecological processes do for the health of the ecosphere as a whole is the root cause of biodegradation and loss. To believe that people and their rights are more valuable than the ecological systems and processes that sustain them is foolish, indeed dangerous, not only to ourselves but to the security of the ecosphere as a whole. The biodiversity lifeboat cannot be less important than its human cargo.

7.1.2 ECONOMIC KNOWLEDGE AND MEASUREMENTS OF BIOLOGICAL RESOURCES

Canada is no different from other nations in that natural resource industries are variously dependent upon knowledge. It does not take detailed scientific analysis to establish resource extractive industries such as forestry, agriculture, and fisheries; the methodology of non-sustainable exploitation can be developed without any ecological knowledge at all. All that is required for "successful" exploitation is the direct observation of the presence and availability of the resource. There are hundreds (possibly millions) of examples in different parts of the planet where this attitude and value system has determined the approach to the commerce of resource exploitation. Such exploitation of biological resources has usually taken place with little or no knowledge of the ecological underpinnings necessary to maintain the resource on a permanently sustaining basis.

In Canada, we have seen several widely publicized examples where available information on population status of important resource species was ignored by managers and political leaders with predictable consequences. Between 1975 and 1993, there was no dearth of scientific data on the deteriorating status of the Atlantic cod "resource". The fixed policy, heavily subsidized by government, led to the predictable crash of the Grand Banks fishery and to the economies of dozens of local towns and villages along the coast of Newfoundland. Likewise, in forested parts of Canada we have seen the abandonment of many "one resource" towns caused solely by the legal pursuit of unsustainable levels of forest harvesting. However, the underlying ecological processes that sustain and produce these fish and forest resources are marginally understood, and studies are generally not supported by Canada's political, industrial, and scientific establishment.

Much of the economic analysis in this report provides estimates of the monetizable value of biodiversity resource products. However, as basic resources become depleted or overexploited, and as society becomes more diverse in its wants and needs, the value of less obvious supporting species, processes, and systems is becoming more apparent. Increasingly, knowledge of the role of these "lesser" species in food chains, of symbioses, of carbon and nutrient cycling, of the maintenance of water cycles and the like is needed to guide development of public policy and management application of resource exploitation technologies, practices and conservation. Research on biodiversity is required for the sustainable management of known (and as yet unknown) supporting species, which are themselves dependent upon the health and ecological integrity of the larger ecosystems that produce biological resources. It is discouraging to report that even when scientific knowledge of trends and of overexploitation levels is available, it tends to be ignored by policy-makers who place priority on creating short-term jobs while ignoring warnings of scientists and economists about the ecological, social and economic consequences of continuing to take the ecological functions of biodiversity for granted.

While this report presents some information on the benefits and costs of Canada's biological resources, the economic significance of biodiversity itself has never been assessed. The economic impacts of biological resource exploitation, transformation, and consumption have been purposefully excluded from this study. However, they are substantial: among others, they include the total value of the agriculture, fishery, and forestry industries.

Apart from providing a measure of the benefits and costs of a diversity of biological resources, the numeric values presented in this report are interesting primarily from a research perspective. The figures represent dollar values for various individual components of our biodiversity; by themselves, these figures do not reflect the total value of Canadian biodiversity. Gaps in our knowledge of the economic benefits and costs associated with biodiversity and its conservation, leave the numbers identified as benefits and costs open to debate and considerable refinement. At this stage, no reliable comprehensive analysis is possible; in fact, such an analysis may never be possible (Glaser and Craig 1994). An array of different socio-economic measures can be used to indicate the benefits and costs of biological resources and their conservation. There is no particular consistency, especially between established commercial sectors and other, less defined sectors such as recreation, ecological fields, in the measures adopted to date.

Figures generated by this research indicate a crude minimal economic value of Canadian biological resources of approximately $70 billion annually, while incomplete costs of biodiversity conservation are crudely estimated at $2.9 billion annually.

There is no universally accepted methodology established for the valuation of biological resources. Each sector approaches the issue of the economics of biodiversity in its own way, reflecting its own perspective of the problem and its solution for that sector. Indeed, it is questionable if a single approach will adequately reflect all perspectives or sectoral needs. However, there is a need for holistic trans-sectoral benefit-cost studies of development's impact on or use of biological resources, particularly as these affect the healthy functioning of the natural world. We should be aware of the environmental, economic, and social costs and benefits of such developments as major hydro-electric power facilities, large-scale clearcut logging projects, or the true effects of extensive toxification of waters or whole landscapes. Generational costs need to be calculated.

The essential point is that long-term economic considerations should play a major role in the valuation of biodiversity and its protection for the benefit of Canadians, and all humankind. The inclusion of economic principles and analyses strengthens any discussion of biological diversity by going beyond the strictly biological to include the values of people and their institutions. It is imperative to incorporate directed economic analysis in future considerations of how to effectively conserve biodiversity. Therefore, in this study, two major conclusions are:

1. biological diversity is *economically* important; and
2. an economic policy framework must be created wherein economic values manifest themselves in a way in which governments and businesses will consider economic values in making their decisions both in Canada and abroad, e.g. depletion of biological resources, inventory, and status of resources.

Some of the funds that are made available to encourage the maintenance of biological diversity should be spent to create an equitable and efficient economic policy framework for resource exploitation internationally. Regulatory initiatives will be necessary, supplemented by economic instruments. However, any country implementing such policies unilaterally places its industry at a competitive disadvantage (in the same way restrictive pollution prevention laws do) and may put national income and employment at risk, although public benefits and options for alternative industries may be enhanced. On the other hand, we see increasingly that products identified as sustainably harvested or produced have competitive advantage. Still, there must be an international will to attain biodiversity objectives, and a common international understanding of what benefits are at risk if action is not taken. It is not so much the amount of any fund available for biodiversity research and conservation that is important, it is the effective use of these funds and the political will to take seriously the protection and management of biodiversity and biological resources. The Convention on Biological Diversity is a unique and potentially powerful global mechanism through which countries can work together to achieve these rational sustainability goals. The delegates of nations at follow-up sessions to the Convention (called Conference of the Parties) need the political will to represent the interests of *all* the citizens of their respective nations, and not act as mere lobbyists for powerful resource sectors back home.

Much of Canada's area is in northern climates, where regeneration of floral and faunal resources is slower than in more moderate climates. This means that more attention should be focussed on the long-term economic effects of exploitation to ensure continued biological diversity. It is especially critical, in a country like Canada, to conserve the fertility, structure, and microbial diversity of basic soil resources, and to avoid further soil and water toxification. There is no doubt that in the long term, the effective and successful conservation of biodiversity and commercial sectoral interests coincide. Short-term actions, which threaten long-term biodiversity and other environmental objectives should not be tolerated. The ultimate proof of success or failure lies in what is actually happening to biological resources and overall biodiversity in the nation's terrestrial, freshwater, and marine ecosystems. Generally, the trends are not positive (Mosquin 1994).

It is because of the lack of consistency and the need to develop credible yardsticks for measurement of a wide spectrum of important values that a number of key options for decision-makers have been prepared (Section 7.2), aimed at developing better methodologies for measuring biodiversity in economic terms.

7.1.3 THE DIRECTION OF FUTURE BIODIVERSITY RESEARCH

The above comments on the value of biodiversity research and the need for new yardsticks for economic measurement of biological resources underline our conclusion that resource management will become increasingly inefficient and difficult unless basic research into the different parts of biodiversity is multiplied manifold. It is a question of priorities. Greater biodiversity knowledge and thinking would lead resource managers, economists, and political leaders to avoid basing public policy, management, and economic thinking and decisions on what little we know today or on false (or no) ecological premises. Such poor decisions are being made around the world; a few of the most disastrous examples are right here in Canada. This situation is further exacerbated by the fact that over the past two decades, biodiversity research in Canada has seen major cutbacks, and a decline in the number of experts as older staff retire and are not replaced.

Basic knowledge of biodiversity begins with biological surveys which reveal what species exist and where they are found. Fieldwork is essential. It includes the sampling of organisms, the building of significant museum collections for comparison, and the maintenance of good data bases. Taxonomic studies require the application of morphological, biochemical, and genetic techniques, and the description of new species, the publication of taxonomic revisions, guides, keys, and distributional atlases. It may include the conduct of ecological and genetic research.

New techniques for studying relationships are now resulting in major breakthroughs in the classification of living things (Margulis and Schwartz 1988; Margulis *et al.* 1989). Good equipment plus facilities for libraries, specimen preservation, herbaria to house scientific collections, and for research are essential prerequisites. However, in the face of the need to shore up knowledge gaps, financial and institutional support for taxonomy is in fact declining (Gaston and May 1992; Gee 1992; Dang 1992). There are fewer university posts each year, and fewer students are able to find jobs. Research proposals in biosystematics submitted to public grant-making research councils (such as the National Science and Engineering Research Council) tend to fall "between the cracks" according to these authors. In the United States, biological research is being placed under a newly formed agency under the Department of Interior called the National Biological Service (NBS) with a bigger budget (Greene 1993). The goal is to compile an inventory of every ecosystem in the United States and its plant and animal species, something that is not being done in Canada.

Understanding how organisms are linked together ecologically, and what they do for one another and the ecosphere, is equally important. The support for ecology, the number of professors and students in universities needs substantial bolstering. How can spaceship Earth be managed if we know fewer than 10% of its parts and understand less than 5% of what they do?

However, a greater understanding of biodiversity alone is not sufficient to ensure its conservation at sustainable levels into the indefinite future. We already know enough to suggest that the best and only way to secure the permanent protection of most of the world's biodiversity is through reductions of human populations, ecologically premised zoning, great reductions in the manufacture and use of toxic substances and well-planned systems of protected areas. Land use planning and zoning, with associated budgets for protection of species and restoration of natural ecosystems are absolutely necessary, or the conservation of biodiversity will be an empty and hollow call.

Knowledgeable persons who are concerned about the negative Canadian and global trends in biodiversity need to work to change philosophies, values and attitudes regarding the management of fisheries, agriculture, and forestry. Environmental laws must be passed which are specifically focussed on ecosystem and habitat protection (rather than vaguely on "natural heritage" preservation). Scale is all-important.

In Canada, few such laws exist. The *National Parks Act* (with its requirement for maintaining ecological integrity) is one recent example of strong government legislation in the direction of supporting the conservation of *in situ* biodiversity.

7.1.4 BALANCING PRESERVATION AND DEVELOPMENT

The conservation of biodiversity and biological resources in any region or nation raises intractable public policy questions about the limits of growth, development, and resource exploitation (Pestel 1989, *Beyond the limits to growth*). Two key questions are: How much development, growth, and destruction of nature would be too much? and How much preservation (of wild species, ecological processes and protected areas) would be enough? Answers to these two questions are legitimate and deserve analysis, since much that is irreplaceable is at stake. Indeed, the Convention on Biological Diversity has been created to address the accelerating losses of the unique natural wealth of biodiversity.

The emergence of biodiversity conservation as a major international issue, coupled with the growth of the science of conservation biology, now provides a scientific basis on which to address this question of balance between exploitation of resources and the preservation of the ecology of the Earth. We are still seeing public policy driving the reduction of biodiversity on lands, fresh waters and marine regions, although there are some recent local exceptions. The balance is still one of increasing losses of biodiversity, not only legally sanctioned but subsidized with public funds.

Just how much of Canada or of any part of planet Earth should humanity leave or attempt to restore to its natural or normal condition? Conversely, how much of the planet's surface should be either converted to direct human uses, or be allowed to be altered or overexploited to the point where few of the natural species are still present and where normal ecological functions can no longer operate?

As noted above, the most effective way to conserve natural biodiversity is through sensible systems of protected areas such as parks, ecological reserves, and the like with land use zoning of buffers and connections to other protected areas. The federal government and the provinces of Ontario, Saskatchewan, British Columbia, Manitoba, and the Yukon territory have all committed themselves to and/or endorsed the goal of protecting a representation of all their natural regions by the year 2000. Should this system of representation be completed, then the total area of natural ecosystems protected would be at least 12% of Canada's territory, which is a crude minimum goal suggested by the World Commission on Environment and Development (1987, 165-166). Regretfully, ecological or biodiversity considerations (such as described in this report) were not considered in making this misleading, highly publicized, and dangerous estimate, which was based on ignorance of the importance of ecological processes.

Ecologists today seem to be unanimous in their view that 12% preservation is grossly insufficient to secure the survival of existing wild species and ecosystems and of the time-tested orderly functioning of the ecosphere. In regions where 12% or less has been protected, many hundreds of species have gradually become extirpated, and their biodiversity functions have been lost due to the increasing pressures and impacts of human factors.

A 12% goal would not mean that representation of each natural region would require 12% of its area be protected. Some parts of Canada would require a far larger percentage in order to ensure the survival of many important area-dependent and isolation-requiring species. But if governments adopt the 12% target as a guideline, and if this includes only those areas receiving high protection (IUCN categories I and II), we would see a much increased level of natural region representation. In fact, of Canada's 177 terrestrial ecoregions, only 22 have more than 12% of their area protected from conversion to human uses. In sharp contrast, 155 of the 177 terrestrial ecoregions and 27 of 29 marine regions are inadequately represented or not represented at all.

These calculations only consider whether a part of an ecoregion is or is not represented. They do not address the far more serious question of what percent of each ecoregion should be protected to maintain regional and global ecological functions, nor do they address the selection of areas for strict protection or special management. These statistics on the sorry state of *in situ* biodiversity conservation in Canada show how far we need to go as a nation to meet the intent of the Convention on Biological Diversity.

7.1.5 A VISION FOR BIODIVERSITY CONSERVATION

How much of the Earth's natural ecosystems should be permanently preserved to retain a healthy ecosphere? The accumulating evidence from the science of conservation biology and from the study of ecological functions (Chapters 2, 3 and 4) appears to be, "the more the better!" From the point of view of providing the needed local, regional, and planetary ecological services, calculations are needed to determine what areas of managed and unmodified ecosystems would maintain these services, and where they should be located. We can now conclude unequivocally that the Brundtland Commission's suggestion of

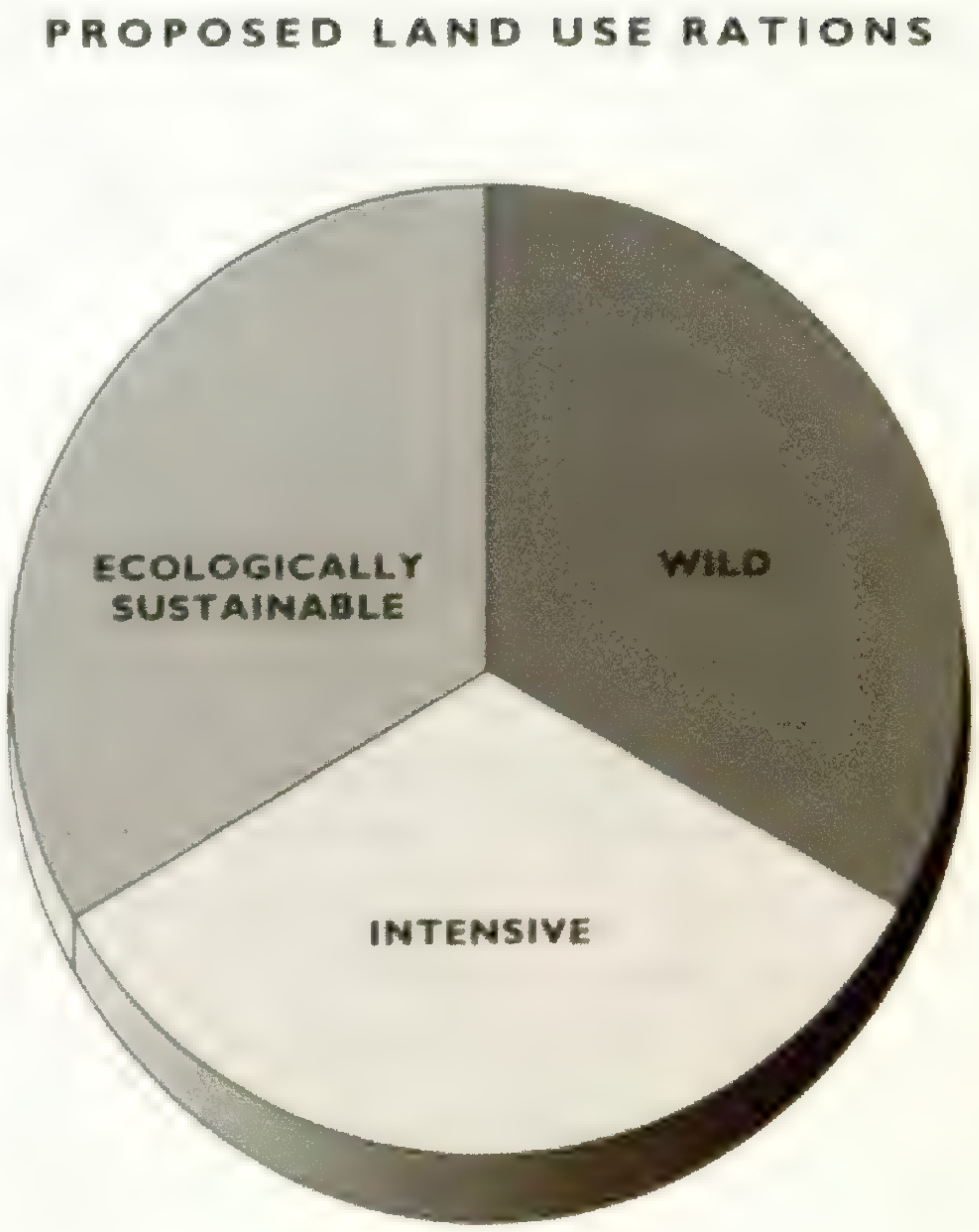

FIGURE 44

Pie diagram showing proposed apportionment of land use in each ecozone amongst wild, partially developed and converted ecosystems (see option 41).

TABLE 13

CONCEPT FOR LAND USE ZONING REQUIRED TO SECURE THE PERMANENT SURVIVAL OF BIODIVERSITY (SEE TEXT)

Category	Ecological Characteristics	% Allocated
A. Normal, high quality natural ecosystems operating with little or no management interference from humans; prohibition of commercial hunting, fishing, and commercial resource exploitation.	Ecosystems follow natural laws as they have for billions of years. Systems are protected and left alone, but humans can visit provided they do not interfere with natural evolution and processes. Locally useful species prevented from going extinct (examples provided by many traditional native cultures). Locally valuable resource species not permitted to be extirpated or go extinct.	1/3 of lands and waters including marine
B. Mixture of 'A' and 'C'. Zoning is critical and based on ecological criteria. Some small towns or cities; systems of required protected areas. Principles of conservation biology widely applied (protected areas, buffers, connectivity, to 'A' above, etc.).	Most ecosystems follow natural laws, all wild species still present but fragmented or variously interconnected. Extensive human management for production of required natural goods (e.g. but no industrial fishing or forestry, instead eco fisheries, eco-agriculture and ecoforestry). Valuation of ecosystems is the basis for management philosophy. Perhaps some electrical power generation.	1/3 of lands and waters including marine
C. Development of major towns, cities, agriculture, industry, aquaculture.	Natural ecosystems scattered and fragmented. Human laws and actions do not jeopardize the ecological health and integrity of either 'A' or 'B' (as they do today).	1/3 of lands and waters including marine

12% protected (implying 88% of the planet's natural systems can be destroyed) is not only grossly inadequate but also a formula for the destruction of the ecosphere's ancient stable norms.

Sufficient numbers of case studies now exist in the conservation biology literature to draw credible conclusions about roughly the percentage of an area or region that needs to be protected or specially managed to conserve normal biological diversity. As well, increasingly, the need for selected buffer zones and required linkages and corridors between such core areas and regions is being documented.

The mechanism for conserving a nation's *in situ* biodiversity is re-zoning of major land, fresh water, and marine areas. The goal is necessarily long-term. New legislation is needed. Existing legislation, official plans and/or bylaws at the federal, provincial and municipal levels must be changed.

The proposed ratios (Table 12) and criteria for preservation versus direct human conversion of ecosystems, suggested by Arne Naess (1989) as "wild fantasy" represents, in our view, a reasonable and minimum protectionist zoning approach that would provide permanent collective ecological and economic security for humans and for the supporting ecological functions of the Earth's biota. We are not at a point of no return. These proposed percentages hold the prospect of stopping the accelerating devastation of life conditions of the land and water portions of the planet.

Admittedly, the achievement of these goals will require major changes in the values of the general public and of influential persons and institutions.

The above proposal implies that humankind try to manage its affairs so that our species comes to live in harmony with nature's ancient processes on two-thirds of the planetary surface, and that only the final 1/3 be allocated for purposes dominated by human wants and needs. Even in this portion, patches of nature would be advantageous to both people and the functioning of the whole.

Odum (1970) suggested that 40% of his home state of Georgia be preserved in or restored to its natural condition. Odum and Odum (1972) proposed a 50/50 split between natural lands of southern Florida and developed lands. Noss (1992) arrived at the figure of 50% and provided detailed rationales. These are the sorts of proposals that, if implemented, would begin a process of reversal of the fragmentation trends over significant ecological regions. They represent the scale of effort required to succeed in retaining the ancient stable natural norms of our planet. Certainly, the alternative—a world of engineered, paved, and polluted landscapes, or of life systems based on technology—cannot be tested for its sustainability and ecological and economic security.

Several attempts at rationalizing and visualizing a protected-areas strategy have been developed in Canada. National parks represent one such vision for the nation as a whole, but the vision has been limited in geographical scope, constrained by past political realities and the wrongful notion that free nature is merely an amenity for human needs and wants. The system of national parks and similar highly protected areas should be increased to 33% of Canada's total area, and should include all ecoregions.

Another contribution toward a protected areas strategy has come from the (disbanded following the 1992 Federal Budget) Canadian Environmental Advisory Council in their publication "A Protected Areas Vision for Canada" (CEAC 1991). The council argued that national and provincial parks, ecological reserves, national wildlife areas, and similarly legislated and zoned lands should be expanded "to fulfil Canada's commitments and obligations to protect species and ecosystems." CEAC published its visionary report before Canada signed and ratified the Convention on Biological Diversity. CEAC's vision anticipated the intent and goals of the Convention.

In addition to the above concept, protected-areas strategies have recently been the subject of concern and interest in the territories and some provinces, notably the Yukon, British Columbia, Saskatchewan, and Ontario. When all is said and done, however, the expansion of protected areas in Canada is a slow, tortuous and uphill process. Useful contributions concerning ecologically based guidelines, rationales and possible scope of a national system of areas to conserve biodiversity have been prepared by experts for the Canadian Council on Ecological Areas (CCEA 1989; Gauthier 1992), an independent NGO working to obtain government and public backing for a national system of rigorously protected representative natural areas. These are small steps along the way to the larger vision of what is required.

7.1.6 HUMAN POPULATION, BIOLOGICAL RESOURCES AND BIODIVERSITY

The rapid rise in human population, increasing by 94 million additional persons each year, together with increasing resource consumption per capita (especially in the North), are the two most important factors undermining biodiversity conservation efforts. Currently, the world's population is 5.5 billion. In August 1994, the World Bank predicted that by the year 2030, this will have increased by almost 3 billion to 8.4 billion. According to the Bank, most of the population growth will occur where the environment is already under severe stress, and in countries where the average person earns less than US $2 per day. No biodiversity conservation strategy can ignore this reality, since it implies a diminishing amount of space for other species, and a further degradation and loss of ecosystems. We are at a stage where the planet's biological resources can no longer provide for the additional numbers of people. Recent analyses of the population issue (Ehrlich and Ehrlich 1990; Statistics Canada 1992a; United Nations Population Fund 1992), indicate the magnitude of the increase and predict a continuation of the upward spiral for many decades.

At the root of the population problem are deeply seated cultural attitudes, and the reluctance of bureaucrats and political leaders to confront the question of human numbers in relation to the sustaining capacity of the planet. Not only in Canada, but in most nations, we see the same paralysis: and increasing, non-sustainable pressure on forests, farmlands, fishing grounds, water, and the atmosphere by ever more industries, industrial agriculture, and new municipalities driven by multiplying human numbers. Whether or not the multiplication of human numbers can be arrested and reversed will determine the condition of biodiversity and the amount of production of biological resources tomorrow. Human survival itself is not at stake, since huge numbers of people are already present in every corner of the planet. What is at stake is the quality of the lives of future individuals and communities. We have seen the future and it is repugnant.

A national population policy to address issues of immigration, emigration, family planning, and international assistance programs needs to be developed as part and parcel of any biodiversity conservation strategy. A related issue is the average per capita energy and resource use (consumption) upon biodiversity. While excessive consumption by wealthier nations is an issue, the possibility of this being reduced appears remote. Hence, a more realistic path is the reduction in the numbers of consumers, a subject beyond the scope of this report. But one conclusion seems incontrovertible, namely, that much of today's existing biodiversity will be greatly impoverished unless governments take action to *deliberately and purposefully* retain and protect it in significant parts of each country and the world. Thus, notwithstanding the continuing surge in population totals worldwide, it is imperative that national networks of protected areas be established while natural areas still exist and their lands and resources are not yet needed to supply basic needs of the billions of new expected persons. Zoning partly developed land for restoration is also necessary in many regions and countries.

The extent to which humans dominate the Earth's landscape can be appreciated from a few figures drawn from McAllister (1993f). If one ignores ice-covered lands and deserts, there is about 1.8 hectares of "usable" land for each of today's 5.5 billion humans. Of that 1.8 hectares, 0.8 hectares are used for crops and domesticated animals and 0.2 for managed forest. This means that humans are actively exploiting 55% of usable land, leaving 45% for all other species and relatively undisturbed ecosystems. Medium estimates suggest the human population will reach 8.2 billion by A.D. 2025. If land use remains constant, in 30 years' time, humans will have exploited 8.2 billion (81%) of the 9.9 billion usable hectares of land, leaving 19% for other species—hardly enough area to provide life-giving services such as clean water, adequate soil and food, climate moderation, and oxygen. Since natural areas and their species provide these vital ecological services, it would be impossible to prevent even more severe environmental and social disasters.

Finally, biodiversity will continue to vanish, and biological resources will continue to be intensely exploited and overexploited, unless their intrinsic, economic, and survival values are taken far more seriously in all nations, rich or poor. People must be educated about the fundamental value of the components of biodiversity. Awareness and improved education can help to overcome humanity's collective inability to value biodiversity, and thus to take action that would reverse its attrition. At stake are the survival of the planet's ecological norms whose time-tested creative workings have always been intimately and intricately determined by the many irreplaceable components of biodiversity described in this report.

7.2 OPTIONS FOR CONSERVING CANADA'S BIODIVERSITY

Following the studies and analyses presented in this report and considering the goals of the Convention on Biological Diversity, the following options for biodiversity conservation in Canada are identified. An option is a forward-looking path or policy that can be chosen to help conserve biodiversity. This chapter attempts to identify what the authors of this report think should be paths or policies worthy of serious public discussion and debate. The options respond to the questions: what should be done, changed, or undone to better ensure the permanent conservation of Canada's biodiversity and to realize ecologically sustainable management of biological resources.

7.2.1 GENERAL OPTIONS

OPTION NO. 1

Human Population and Biodiversity

Rapidly increasing human population is the prime cause of the loss of biodiversity the world over. To successfully address the depletion of biodiversity and biological resources, we must address the question of population. Indeed, were it not for the imbalance between the size of the human population and the resources necessary to sustain it, there be no need for an international convention to conserve biodiversity. Among most nations, there is little action to reduce populations so that sustainability would be possible. Humans are already drawing upon a full 40% of primary productivity of terrestrial ecosystems. It is impossible to expect planetary biodiversity to support such populations of people. As population growth continues, many more species will be deprived of the space and resources necessary for their survival. This concern applies equally to all nations.

Canada (and all nations), should develop a national population policy that is aimed at first stabilizing and then balancing (by reduction) this nation's total population with environmental constraints. Canada should renew its commitment to work with the United Nations to enhance the status and education of women and to expand the availability of the world's family planning and educational services. As well, it is logical and essential that the Canadian government support other countries in their efforts to also reduce and stabilize their populations.

OPTION NO. 2

Public Valuation of Biodiversity

The conservation of biodiversity obviously requires that people recognize its value. Values seem to have three intertwined sources, two in the observer and the other in the observed (Jonathan Miller. "The Nature of Emotion". Chapter 8 in *States of Mind* 1983. Pantheon Books, New York). The first is the powerful cultural source, comprising all the learned likes and dislikes of particular societies and religions, transmitted by language and other symbols. The second source of values is genetic, the instinctive likes, dislikes evident in infants. The third can be called the objective source, comprised of all apparent emanations from the thing itself (in this case biodiversity). It is the first source of valuation that can be affected through education, experience, public policy changes and media communications. The third source is also critical since the complete destruction of biodiversity in an area or region means that people cannot even know of it or experience it first hand.

Canada's National Round Table on Environment and Economy (1992) identified "values" as being critical to the conservation of biodiversity. A key option is to change educational and communications materials to increase the public's fragmentary knowledge of the values of biodiversity. In particular, the values of ecological functions and processes of biodiversity in supporting the harmonies, health, beauty, and productivity of the planetary ecosphere (and thus its deeper value to humanity) require urgent attention. Information on the nature and meaning of biodiversity, and its determining control over biological resources needs to be made widely available so that informed public debate on the values of biodiversity can take place

OPTION NO. 3

Strategies and Action Plans for Biodiversity Conservation

Because jurisdiction over biodiversity and biological resources in Canada is divided among the provinces and the federal government, the conservation and sustainable use of biodiversity will be more difficult to achieve unless each province develops its own biodiversity conservation strategy and action plan that is consistent with the national strategy.

Therefore, each province and territory should follow the lead of both British Columbia and Quebec in initiating a process that can lead to biodiversity conservation plans for their respective jurisdictions. Since municipal governments control private land uses through zoning bylaws and official plans, the option of modifying planning legislation and procedures at this level should obviously be reviewed.

OPTION NO. 4

Developing a Life Quality Valuation Methodology

Purely economic measures of biodiversity values miss much of what is meaningful and beautiful about life and our eternal search for happiness. A number of relative value schemes have been developed to assess the quality of life of people within and between countries. Essentially, such schemes assess the intrinsic values of biodiversity. Some examples are: happiness, natural beauty and good health that many derive from being close to nature; wilderness experiences; drinking from or swimming in a mountain stream; knowing about the successful preservation of a rare or beautiful species; walking through an old forest; snorkelling in a kelp forest, around a coral reef, or in a lake rich in aquatic life; observing a child's discovery of a shell or butterfly. The absence of these experiences in a person's life has major implications to society. Application of such an evaluation methodology in different parts of the country and in local communities could provide new insights and rationales for the conservation of local and regional biodiversity, and would make it easier for ordinary people to help achieve the intent of the Convention on Biological Diversity. This suggested option would see some of our governments review the various "quality of life" evaluation methods that have been proposed, and adopt them as goals/standards to be achieved by Canadians.

7.2.2 BIOLOGY OPTIONS

OPTION NO. 5

Ecological Research

Understanding what biodiversity is and how it functions to create the world's terrestrial, freshwater and marine ecosystems as we found them, is an essential prerequisite to enlightened conservation and management of biodiversity, and to the sustainable use of biological resources. One option that could achieve such an enhanced state of enlightenment is that calling for significant new support for the acquisition of ecological knowledge about Canada's biodiversity.

The reality in Canada, however, is that research into the ecology of species and the functions of ecosystems is scattered, fragmented, and given low priority, a situation impossible to justify given our knowledge that biodiversity is critical to the health of ecosystems and the ecosphere, and to humanity's wealth and quality of life.

Ideally, the ecological research option should include work within each of the 177 terrestrial ecoregions and in all marine ecoregions (or in provincially defined equivalent natural regions) of the country.

OPTION NO. 6

Organization of Taxonomic Science at Ottawa

An idea that has been discussed for many decades is that all Ottawa-based federal scientists working in the taxonomy of biota (see Appendix 1 for a list of taxonomic groups that exist in this country) would be greatly advantaged by being located at a single institution. Today, taxonomists are located in a number of different institutions: the Canadian Museum of Nature, Agriculture Canada, Environment Canada and the National Research Council. Considering the pervasive connectivity that exists between and among all living organisms, Canada should examine the option of bringing these federal experts into a single location to substantially increase the excellence of research and effectiveness of dollars spent. Integration of publications, collections, data bases, library and other services, would naturally follow, offering cost savings by eliminating duplication. Such an institution should be charged with responsibility to provide the country, and the emerging bio-industries that depend on basic taxonomic knowledge, with broad advisory services aimed at better biodiversity conservation and ecologically sustainable use.

Most provincial natural history museums have limited staff for conducting biodiversity-related research and services.

OPTION NO. 7

National Taxonomic Biodiversity Inventories

This study has identified the concern that Canada is not conducting enough research into taxonomic biodiversity to complete the inventory of species found here. About half of Canada's species are not yet scientifically described, while the distributions, ecological requirements, and abundance of many species are poorly known. In particular, the biota of soils, lower plants, the invertebrates and micro-organisms of marine and freshwaters are very poorly known. Taxonomic knowledge of the existence of species in all groups present in any areas and associated knowledge of the ecosystems in which they live, logically forms the essential building blocks of credible long-term biodiversity conservation strategies. Such knowledge is also essential for enlightened management of important resource species. As well, teaching and training of students at universities are essential prerequisites for overcoming the shortage of personnel to carry out this kind of work. The current level of taxonomic research is inadequate to the completion of basic inventories of species in all groups identified in Appendix 1.

The unfortunate irony of Canada's investment in taxonomic biodiversity research is that the numbers of research scientists are being reduced and training programs are receiving cutbacks at precisely the time when the Convention on Biological Diversity has been ratified by this country, and the discovery has been made that almost half of our species are not yet described by science. Hence, a clear-cut option should be to review this whole matter in light of the Convention.

OPTION NO. 8

Effects of Pollution on Biodiversity and Biological Resources

Across Canada, pesticides, herbicides, acids, and other toxic chemicals are being dispersed through activities in agriculture, forestry, industries, municipalities and by private property owners. It is essential that the option of drastically reducing dependence on these toxics be seriously examined. Collectively, these toxic are weakening or destroying the bases of major food chains. They are having a major negative impacts on the quality of air, water, and land required for the health of organisms and ecosystems. Their continued use is undermining the normal functioning of Canadian and global biodiversity. Canada's Green Plan proposed a goal of zero discharge of persistent toxic substances but did not provide a target date. The federal and provincial governments need to work to reduce and eliminate the uses of toxic substances and inorganic fertilizers with the goal of restoring local and regional biodiversity, and to allow for the recovery and self-cleansing of biological and other resources (soils, ground waters, lakes, streams, oceans, fish, etc.). The goal should be zero discharge of all persistent toxic substances by the year 2005 and their eventual permanent ban from the living space of the Earth. Only ecologically benign alternatives should be manufactured.

OPTION NO. 9

Protected Areas and Biodiversity

The most critical on-the-ground option for conserving biodiversity is through national and international systems of variously protected areas combined with areas where sustainable use is practiced. Canada has the potential for setting a good example—similar to our role in peacekeeping. National and Provincial Parks, ecological reserves, nature sanctuaries and other strongly protected core areas offer the best-known institutional mechanisms of conserving biodiversity. Yet, a glance at a protected-areas map of almost any part of Canada reveals that the option of using protected areas to conserve biodiversity is not being exercised.

In its Green Plan, the federal government announced its commitment to completing Canada's National Park system by the year 2000. As well, some provinces have pledged to protect ecosystems in at least 12% of their jurisdictions. The 12% is considered a minimum prerequisite percentage for sustainable development according to the 1987 report of the Brundtland Commission. The

World Wildlife Fund (Canada). However, see Section 7.1.5 and Option 41.

Obviously Canada-wide systems of protected areas, buffers, and corridors connecting protected areas need to be central elements in the strategies. This approach requires ongoing and permanent federal-provincial co-operation, and integration of biodiversity conservation policies and programs with those of the provinces. The Convention on Biological Diversity calls for wealthier nations to work with the poorer countries to conserve biodiversity beyond our national boundaries. Canada should promote the establishment and enlightened management of protected areas in developing countries by helping them to identify the most suitable areas for biodiversity conservation through the establishment of parks, nature reserves and other protected areas.

OPTION NO. 10

Ecoregions as a Means of Conserving Biodiversity

The federal government's ecoregion framework provides a good basis for selecting areas where Canada's different kinds of ecosystems can be allocated for the purpose of biodiversity conservation. Today, 45 of Canada's 177 terrestrial ecoregions have no protected areas at all, and in some, the protected areas are too small to be truly effective. Marine ecoregions have been only superficially defined and mapped. Clearly, the option of using the ecoregion framework to select and designate areas for biodiversity conservation is open to federal and provincial governments. The political will, however, is sometimes lacking.

OPTION NO. 11

A Unified System of Ecological Zones

Canada and the provinces have their own versions of ecoregion boundaries. This is neither logical nor scientifically sound. A common, agreed-upon national/provincial/territorial system would foster protection and/or restoration of the full variety of our ecosystems. It would mean better co-operative actions and programs, and would unify the various governments' conservation efforts. All provinces, territories, and the federal government need to work toward the development of a single unified system of ecological zones boundries.

OPTION NO. 12

Endangered and Threatened Species

An option that would help implement the Convention on Biological Diversity in Canada would be the passage of federal legislation respecting the protection and rehabilitation of natural ecosystems required for the survival of threatened and endangered species.

Canada already has several mechanisms in place to make decisions on the status and rehabilitation of species that might be threatened or endangered. One of these is called the Committee on the Status of Endangered Wildlife in Canada (COSEWIC); the other is the Committee on the Recovery of Nationally Endangered Wildlife (RENEW).

A private members' bill (Bill C-275) was tabled in the House of Commons on September 28, 1994 to provide a legal and financial basis for the work of these two committees. As well, a national coalition of environmental organizations has been pressing the federal government to initiate the drafting of an Endangered Species Act. As of August 1995 the Federal Government had drafted a "Plain Language Bill" and is completing a legislative proposal. Such legislation would be consistent with Canada's obligations under the Convention on Biological Diversity. Public consultations on this matter are expected in late 1995.

A current weakness in the work of COSEWIC and RENEW is that determination of the status or the rehabilitation of important invertebrates, algae, fungi, micro-organisms, and such, is excluded by policy. These taxonomic groups are ecologically important, particularly when their species are thought to play keystone roles in natural ecosystems, as for example in food chains that underpin the production of important biological resources. Hence, an important option for the future scope of the work of COSEWIC and RENEW is that the two committees should be able to include any species of living biota, regardless of taxonomic relationship, and that their work be set upon a firm legislative basis.

OPTION NO. 13

Biodiversity and International Trade in Wildlife

At present, customs officials are not required to ask travellers to record the contents and value of wildlife species, parts, or products moving into or out of Canada. Such documentation would help determine the dollar value benefits of trade and the significance of trade in wildlife products. Canada must develop a better system for accounting for the export and import of wildlife and wildlife parts and products at Canadian border points. It would make sense that a significant percentage income from the value of this trade (for example, 50% of duties, license fees, etc.) be spent by the provinces on biodiversity conservation programs.

OPTION NO. 14

Understanding Marginal Populations

Populations of species living at the extreme limits of the species' geographical range are likely to have unique adaptive properties essential for survival. This is particularly true of plants and those animals and microflora and fauna that are non-migratory. The location of such populations should be known so that they can be protected from extirpation. Marginal populations may have particular significance in times of global warming. They provide a source of more highly adapted genes for the rehabilitation of other lost populations. Canada should develop specific research programs to support genetic research into the nature of unique adaptive traits of such populations.

OPTION NO. 15

Introductions and Ecological Impacts of Exotic Species

The serious impacts on native biodiversity of the deliberate or unintentional introductions of exotic species have been outlined in this report. Exotic species not only displace native species, but in doing so, they impair the ecological functioning of native species and ecosystems. Canadian laws and regulations respecting such introductions are too lax. The following options are outlined to help reduce the incidence of such introductions in the future:

a) introductions of exotic species liable to spread into a neighbouring province or state should not be attempted without permission of that neighbour;

b) exotic species should not be intentionally introduced without prior studies on the potential impacts, and such studies should be required in federal and provincial environmental impact legislation;

c) introducers of exotic species should be liable for negative impacts from intentional introductions;

d) additional steps should be taken to prevent unintentional introduction of exotic species in ballast water or by other methods;

e) specific provincial educational materials should be developed to teach about the consequences of exotic species introductions; and

f) research into the geographical and taxonomic extent of introductions, and the ecological damage being caused to native biodiversity by exotic species of animals and plants should be more strongly supported.

OPTION NO. 16

Common Data Bases for *Ex Situ* Collections

As described in this report, many of Canada's *ex situ* institutions have incomplete computerized data bases, and are unable to provide accurate lists of numbers of species, varieties, cultures, and provenances held in their collections. Integrated data bases will make these collections and their data more widely available for conservation, research, agriculture, medicine, etc. Computerized data bases for all *ex situ* collections need to be completed and accurate lists of holdings be available.

OPTION NO. 17

Conservation ofThreatened and Endangered Species in Zoos, Game Farms, and Botanical Gardens

Surprisingly few threatened or endangered species are now being raised in Canada's *ex situ* facilities. Additional efforts by zoos, game farms and botanical gardens would help achieve the goals of the Convention on Biological Diversity and of national and provincial biodiversity conservation strategies. The work should aim at complementing the work of COSEWIC, RENEW and the aquatic Conservation Network. A common data base into which all private and public facilities contribute would facilitate the efforts and reduce costs of all.

OPTION NO. 18

Role of Botanical Gardens in Ecosystem Restoration

It is logical that botanical gardens work in consort with provincial agencies and private conservation groups to restore natural ecosystems in regions where extensive areas have been converted to human uses—such as southwestern Ontario, the southern prairies, and the lowland valleys of southern British Columbia. In this study we found that none of the facilities or species in Canada's botanical gardens (Section 5.10) had ever been used for ecosystem restoration. Botanical gardens are logical places from which to direct restoration and rehabilitation work.

OPTION NO. 19

Reference Collections for Small Invertebrates and Micro-organisms

This study found that (with the exception of larger organisms) invertebrate groups were poorly represented in scientific reference collections. At the same time these smaller organisms are crucial components in almost every ecosystem. Established institutions such as Agriculture Canada, the Canadian Museum of Nature, provincial museums, and other research institutions should create and/or expand comprehensive reference collections of invertebrate groups and microbiota, particularly for their areas or regions of jurisdiction. Of course, this cannot be done without access to collection facilities, space, and associated scientific and support staff. Records would need to integrated, either physically, or in common computer data bases as required. As well, consultants, industry or government staff involved in environmental impact studies should be required to place voucher specimens in established institutions for permanent safekeeping and future research.

OPTION NO. 20

Monitoring the Components of Biodiversity

As outlined in Chapter 2, there are five inseparable parts to biodiversity: genetic, taxonomic, ecosystem, ecological functions and "abiotic". Present monitoring of environmental indicators (Environment Canada 1991b) focusses mainly on the "abiotic" component of biodiversity (i.e. pesticides, toxics, soils, waters, air, etc.). As well, a few economically or recreationally important species are monitored. But neither the species that underpin the productivity and health of ecosystems, nor the ecological functions that they carry out are monitored. For example, fishing bank habitat is not monitored. The most critical indicators of the "state of biodiversity" must apply tests to biodiversity itself, and not be limited only to trends in toxic chemicals, water, soil, or air quality as such, although the latter do indicate what is happening to the abiotic matrix of biodiversity. It seems logical that monitoring include biota of representative farm and forest soil sites, rangeland, and fishing grounds (particularly for sessile, infaunal, and nectonic organisms), as well as changes to biota in natural areas. In the meantime, the entire question of what components of biodiversity ought to be monitored and how they should be measured should be professionally reviewed.

OPTION NO. 21

Biosphere Reserves

Biosphere reserves provide a unique way of attempting to reduce the impact of human use upon the biodiversity in a particular region. Six regions of Canada have now been accorded biosphere reserve status. Our review of the idea of biosphere reserves suggests that about 10 more such reserves should be established so that all of Canada's major biogeographical provinces are included. Currently, the north and marine regions lack significant (or any) representation.

OPTION NO. 22

Private Sanctuaries and Nature Trusts

At present, the federal government and the provinces do not encourage the creation of private sanctuaries and nature trusts for the protection of wild species and ecosystems (i.e. for the conservation of biodiversity). The provinces lack strong, encouraging legislation, while the federal taxation system places major obstacles in the path of private landowners wishing to allocate their lands for this worthy purpose. In our view, about one-third of Canada's private lands should be dedicated to the conservation of biodiversity, free from taxation, and free from deemed capital gains tax when they are donated for biodiversity conservation purposes.

This option for biodiversity conservation would have major consequences. Governments need to provide the essential legal and tax mechanisms. The path to follow, obviously, is to re-examine and strengthen the institutional and legal mechanisms to allow private land owners to protect their lands from development or exploitation through permanently binding covenants and conservation easements. There would be an obvious need for sound ecological studies prior to such designations, as well as criteria and standards for acceptance and management.

7.2.3 ECONOMICS OPTIONS

OPTION NO. 23

Socio-economic Indicators of Value

While Canada has developed many indicators of biodiversity and resource values, there is an urgent need to develop a better methodology and a consistent set of national and international socio-economic indicators of these values, and a further need to implement a system to monitor these indicators over the long term. An important option for biodiversity conservation is that Canada, in association with other countries, develop more understandable, comprehensive, and generally better indicators of biodiversity and biological resource values.

OPTION NO. 24

System of National Accounts

Wild fish stocks, natural forests, ground water "banks" and agricultural soils that have been created by natural processes over thousands of years, represent some of the real wealth of a nation. It is logical that the depletion of or addition to fish, trees and soils should be reflected in measures of

Canada's worth. Hence, Canada should extend its existing system of national accounts to include measures of annual changes in the depletion of and addition to Canada's principal biological resources.

OPTION NO. 25
Analysis of Invisible Biodiversity Functions and Values

Wild species and natural ecosystems play vital roles in sustaining themselves, their immediate surrounds, their communities, local and regional ecosystems, waters, soils, the atmosphere, and the ecosphere as a whole. It is logical that Canada carry out more concerted research into the economics of that part of biodiversity currently having no quantified monetary resource value. More specifically, this would entail a serious analysis of the economic costs/values/benefits of the 21 ecological function values outlined in Chapter 4 of this report. In effect, such research would serve to clarify the largely invisible (but controlling) "economy of nature." It would provide unique background information on which to formulate more realistic policies for ecologically sustainable development. In our view, all hopes for sustainable development are misplaced unless the invisible functions of myriads of small organisms in all ecosystems are retained and/or restored. As well, the proposed analysis would shed useful and essential light on the actual and potential economic value to society of maintaining the five parts of biodiversity (Table 1) in a healthful, productive, and non-toxic (i.e. normal) condition in perpetuity.

OPTION NO. 26
Methodology for Determining Option and Existence Values

Option and existence values are generally excluded from most economic valuations of biodiversity because of shortcomings in measurement and methodology. The development of a consistent valuation system would mean that recreational, ecological, and other uses of biological diversity that are either non-commercial or inseparable from other activities or sources of benefits would be included in the economic values. Hence, an option for helping with the conservation of biodiversity would be to expend additional efforts on the development of methodology and tools to derive option and existence values of biodiversity. These would be valuable to governments, businesses and non-governmental organizations.

OPTION NO. 27
Eco-tourism and Biodiversity

Canada and other nations are considering developing an eco-tourism industry as a way of generating economic activity. However, the economic values of eco-tourism developments in relation to biodiversity conservation are inadequately understood. Some eco-tourism projects can do far more damage than good to an area's biodiversity and to the general environment. Similarly, the obvious importance of biodiversity to the success and expansion of eco-tourism is not well documented. Evaluation of the environmental consequences of eco-tourism should include transport of the tourist, provision of all necessities, effects on local peoples and their cultures, and effects on wildlife populations. It is our view that the term eco-tourism should be reserved for low impact tourist activities that enrich a person's experience with, understanding of, and empathy for nature while at the same time leading to greater protection or restoration of the "eco" part of eco-tourism.

It is prudent to understand the full scope of the impact of eco-tourism on biodiversity and the environment. Therefore, an option in this regard would be to define and economically assess all the effects of eco-tourism activities or proposals upon both biodiversity and the economy. Further, research on the economic and cultural significance of biodiversity to eco-tourism should be fostered.

OPTION NO. 28

Socio-economic Information on Parks and Protected Areas

This study found that socio-economic information on the biodiversity values of protected areas such as provincial and national parks, publicly held natural areas, and private nature sanctuaries is scattered, incomplete, or non-existent. Information that provides insights into the benefits of biodiversity conservation through protected areas needs to be substantially augmented.

OPTION NO. 29

Forestry Resources

Canadian forests provide an estimated 7.5 billion dollars in annual sales of raw forest products. With some exceptions, the impacts on forest biodiversity are profound. Industrial forestry practices still involve large-scale clearcuts, clearcutting on steep slopes, removal of stream-side vegetation, the application of pesticides, the burning of logging slash, and the continuing fragmentation of remaining forest wilderness needed by many species for their survival. These industrial practices affect biodiversity through soil erosion, stream siltation, loss of beneficial soil biota, loss of humus, effects on micro- and macroclimate, and loss of major habitat, Current management policies tend to ignore non-fibre forest products and focus on volume extraction of raw lumber and paper pulp. Industry diversification through value-added processing and enterprises, development of new, natural biotechnological and pharmaceutical products from the forests, and the associated employment that such industries could bring to local communities are generally not encouraged. The general approach in Canada is "cut and run." As well, pesticide applications, reforestation with single species or genetically modified stock are slowly reducing biodiversity in ever more regions. Major new regions of Canada are being cut or targeted for future industrial forestry.

If biodiversity conservation is to be a goal in Canada's forest management, then the single most important option for the nation's forestry sector is to move from industrial forestry to eco-forestry, which aims at managing forest landscapes so as to retain overall ecological integrity in a region. In developing and using more ecologically sustainable methods, the goal would be to sustain other benefits and ecological functions of the forest, and maintain permanent employment in local communities. Eco-forestry emphasizes selective logging, logging in small patches, or in narrow strips along contours. It requires the retention of core protected areas, buffer areas and connections between core areas. These are questions of national and provincial forest management policy.

OPTION NO. 30

Fisheries Resources

As with forestry, the fishing industry has developed large, powerful gear and ships equipped with sophisticated navigation and fish-finding technology, whose harvesting capacity has out-distanced fisheries regulation and management. Slender population buffers (or none) leave little capacity to respond to overexploitation or to environmental changes such as climate, increasing ultra violet radiation, or increasing levels of toxic substances in ocean and fresh waters. Trawlers generate enormous bycatches with unpredictable effects on non-target biota, as well as indirect effects on target species. Fish, shrimp, and shellfish trawls/dredges impact thousands of square kilometres of fishing banks, drastically altering the ecology of the ocean floor.

The management of commercial fish species has been given high priority in Canada, and tens of millions of dollars have been spent on censuses and licensing the level of harvest. However, enormous depletions of cod, haddock, bluefin tuna and other species have resulted, causing the loss of important biodiversity and collapse of the economies of local communities. Our knowledge of the status of marine resources, the ecological damage being done and the role of oceanic food chains is poor (except through catch statistics). The widespread use of industrial trawler and electronic technology has depleted economically important fish species on both the Atlantic and the Pacific fishing banks. Such technology has proved to be incompatible with the conservation of marine biodiversity. Only with sustainable harvesting technologies (long lines, cod traps, or significantly modified mobile gear, etc.) will it be possible for biodiversity to return.

Hence major options are:

- to select and develop fishing gear that, while economically and socially remunerative, minimizes bycatch and habitat impact;
- to develop and introduce more diverse sustainable and environmentally less damaging ways of harvesting marine resources;
- to work to develop more marine ecotourism as a non-consumptive use of marine biodiversity; and
- to develop environmentally friendly marine bio-industries, such as the production of compounds having biochemical and pharmaceutical value.

OPTION NO. 31

International Management of Fisheries

It makes economic sense that fisheries resources be managed with the goal of restoring and retaining productivity and ecological integrity of fishing grounds. A desirable and clear cut option in pursuit of this goals is that international management of fisheries and marine resources on continental shelves be ecologically based. This will mean a major shift in funding priorities for fisheries management toward supporting fundamental ecological research to discover what enabled natural systems to work so well and the past with the objective of restoring degraded systems. As many as several hundred research scientists with appropriate support facilities and budgets should be assigned to this urgent task. The traditional knowledge of fishers, fishing communities, and indigenous peoples could be drawn upon to complement scientific knowledge.

OPTION NO. 32

Changes to Agriculture

Around the world, agriculture has been the most significant human activity responsible for the destruction of global biodiversity. To work toward achieving the goals of the Convention on Biological Diversity, agriculture would have to be rolled back. This would require a re-thinking of long-accepted values deeply associated with the "clearing" of land, the use of pesticides, the exhaustion of soils, the real value of wildlife habitat in farming areas, the real impact and value of farm subsidies, and other factors. While these sorts of reversals in agricultural policy would be opposed by some agricultural interests, they should be openly discussed. If policies and value systems respecting the impact of agriculture on the world cannot be altered, then the effective conservation of biodiversity in rich agricultural areas will not be accomplished and agriculture will continue to be a large part of the problem. While recognizing that monoculture might be necessary for short-term, on-site commercial efficiency, consideration of the long-term economic values of maintaining biologically diverse agricultural resources and reducing off-site impacts on natural ecosystems and human health will help identify future resource management options and approaches that are economically, environmentally, and socially sustainable.

Current industrial agriculture focusses on cultivating, over large areas, single varieties of genetically homogeneous crops and domestic animals. The gradual negative trend in agricultural regions has been multiplication of pests, exhaustion of soils, increased application of pesticides and chemical fertilizers, overtillage of the soil and compaction. These management techniques have resulted in a decline in beneficial soil biota, lowered humus content, reduced soil porosity, eutrophication of waterways, and increased soil erosion.

The most important biodiversity conservation option for Canadian agriculture, is to encourage, develop, and apply ecologically less destructive methods of farming and to disallow or discourage any further land clearing, such as that in northern Alberta. Options to the current approach include polyculture, increased genetic variability within seed plantings, more varieties adapted to local and regional conditions, attention to soil biota and health, and use of biological controls and organic fertilizers. Agricultural research could be redirected to develop farming methods with low impacts on biodiversity of the soil and aquatic ecosystems. Regulations, tax systems, and subsidies would need revision to help attain these biodiversity conservation and restoration goals.

OPTION NO. 33

Determining Expenditures on Biodiversity-related Research

A great deal of research termed "biological" is unrelated to the conservation of biological diversity. Indeed, much biological research today is designed to exploit, destroy, control, or in some way use up existing biodiversity in the service of human health, convenience, utility, power, or profit. Biodiversity-related research constitutes only a small fraction of biological research expenditures. It includes the genetics and reproductive biology of wild populations, taxonomy, ecological processes and functions, conservation biology, and the elements of seascape and landscape ecology, all of which together provide the information base and knowledge needed for enlightened policies of biodiversity conservation and restoration and for the ecologically sustainable use of biological resources.

Governments already have in place various programs and policies that have the effect of protecting some biodiversity, but research expenditures more directly related to conserving biodiversity are not known. In view of the Convention on Biological Diversity, they should be. Assessing and classifying these expenditures would aid in the classification (determination) of benefits and associated costs.

An option, therefore, is for governments of Canada and the provinces to determine total expenditures on research that has direct relevance to the conservation of biodiversity as a percentage of total biological research.

OPTION NO. 34

Costs of Current Conservation Measures

Costs of current conservation measures are neither well understood, nor well documented.

An option therefore exists for the undertaking of a proper and full accounting of private and public costs associated with the conservation of biodiversity. The parameters for documenting these costs should be defined and a methodology to determine them be developed. The contributions and costs (expenses) of non-government organizations for the conservation of biodiversity should be determined by examining the budgets and extensive volunteer input of all these organizations and their staff. Likewise, the costs of failing to carry out conservation measures should be calculated to evaluate cost-effectiveness of conservation measures. The value of the "free" ecological functions, as described in Chapter 4 of this report, should be included in the calculation estimates.

OPTION NO. 35

Estimating True Costs of "Greening" Production

The full costs associated with major sectoral changes that result in less destructive or "more natural" production of goods and services are immense; yet they have not been estimated in this report. The task of estimating the true costs associated with major sectoral changes that lead to increased "natural" production should be studied.

OPTION NO. 36

Estimating Costs of Non-conversion to Friendly Technologies and Resource Harvesting

The costs of *not* converting to environmentally "friendly" products and processes may be high. Inaction could result in health impacts, loss of biodiversity options, loss of markets, unemployment, decreased competitiveness and rejection of products (British Columbia lumber; Canadian furs, etc.). Hence, it is recommended that realistic costs of non-conversion to environmentally friendly processes and products be determined.

OPTION NO. 37

Benefits of Industrial "Greening"

Out-of-sector benefits of "greening" of many industries have not been evaluated in this report. There are many undetermined spin-off benefits to the conservation of biodiversity. Canada should determine the true values of these benefits such as edible freshwater fish, higher production of forests, retention of biodiversity use options, better growth of agricultural crops, and increases in human health as determined by lower medical expenses, and so forth.

OPTION NO. 38

Costs of Overexploitation of Biological Resources

When government policies encourage or allow commercial interests to overexploit biological resources, or when these policies subsidize the creation of jobs at the expense of the production of biological resources, enormous costs are incurred for present and future generations. The notion that many past developments or resource exploitation programs were mistakes—both socio-economically and environmentally—may be hard for advocates of such exploitation ideologies and policies to accept. The collapse of the cod fishery has caused enormous, economic hardships on communities along the Atlantic coastline. Similarly, the past overexploitation of Pacific halibut fishery, and the abandonment of major towns in overcut forested areas of Canada, provide good examples of the effects of short-term overexploitation of resources. These are also examples of the results of subsidized mismanagement. The economic benefits have been estimated in this report, but the economic and social costs to society (real estate losses, unemployment insurance, etc.), have not been discussed. The failure to log sustainably, to encourage natural regeneration or to replant logged areas of forest can be seen as a long-term loss to the forest industry and to the economies of local communities.

An option that would aid in the conservation of future biodiversity would be to determine the economic costs of over exploitation of biological resources. The estimate would provide a measure of what society must pay for such policies.

OPTION NO. 39

Assessment of Cumulative Effects

Increasingly, it is being recognized that single developments in themselves may have limited impact upon biodiversity and the human environment. However, the cumulative effect of such developments over time and space can cause serious, negative changes in local and regional biodiversity, the environment and associated human economies. The general acidification and toxification of lands and waters is one such example. Another would be the addition of yet one more pulp mill on a major river that already has two—the result of which could be far greater impact on biodiversity than the combined impacts of the first two mills. A third example would be the combined marine impacts of hydroelectric developments, with emissions and discharges of water, such as in the James Bay region. A fourth would be the dumping of a dozen more synthetic chemicals into a river or lake system, each at an established "safe" level but where synergistic effects could suddenly cause major losses or changes to aquatic biodiversity. Impacts must be recognized more fully through increased efforts at measuring these cumulative effects.

A major option for consideration, therefore, is that studies be funded to increase scientific and economic research on the cumulative effects of resource development initiatives on Canada's biological diversity.

7.2.4 FUTURE CONSIDERATIONS FOR BIODIVERSITY

OPTION NO. 40

Additional Economic Analyses

In addition to several other areas, the following topics related to biodiversity conservation are particularly difficult to analyze because of the lack of accessible, organized data. They should be considered for future research:

- economic benefits and costs derived from micro-organisms;
- value of nature art, films, videos, and publications on biological/natural resources, particularly as related to biodiversity;
- therapeutic value of contact with nature through recreation, and nature-based activities;
- subsistence values (wildlife and plants);
- aquaculture values;
- pharmaceutical values; and
- values of marine plants.

OPTION NO. 41

Ultimate Goals for Biodiversity and Biological Resource Conservation

The Earth's biodiversity and biological resources are being thoughtlessly and excessively overexploited and degraded at unprecedented and accelerating rates. Humanity's quality of life and ecological security are being reduced. To continue to pursue policies that result in humans being even more disconnected and separate from the time-tested survival rules of natural ecosystems and the ecosphere is short-sighted, and threatening to our collective future—a miserable future that has already arrived in many nations. The flourishing of human and non-human life has inherent and intrinsic value; the destruction of biodiversity, simply because it does not yet have some resource value, is wrong. The overexploitation of existing resources is wrong.

This option for action recognizes the long-term goal and purpose of biodiversity and biological resource use and conservation, namely to ensure the survival of humankind and all companion species and ecosystems within what has been (until now) an ecologically secure and stable ecosphere.

The federal and provincial governments should co-operate in developing nation-wide, long-range biodiversity and natural resource land use zoning plans (looking forward at least seven generations or even to the year 3000), with the goals of securing permanent protection for biodiversity, maintaining ecological processes, and using biological resources in an ecologically sustainable manner.

As well, the provincial and federal governments should co-operate to develop land use legislation, policies, and zoning aimed at the ultimate goal of allocating about one-third of the lands and waters in each ecozone (or provincial equivalent) for the purpose of retaining and/or restoring wild species and natural ecosystems where the laws of nature would operate (as they have in the past) without major human intrusion. The second one-third would require land use planning and management (of ecosystems and people) in ways that would allow permanent sustainable extraction of biological resources, while retaining most wild species and the normal ecological functions and services of biodiversity. The final one-third could be zoned mainly or entirely to meet humanity's essential productive and living needs, permitting intensive use subject to rules and regulations that would prevent serious impacts upon planetary norms.

OPTION NO. 42

International Aid for Biodiversity Conservation

Only with financial assistance from wealthy nations can many countries attempt to implement the provisions of the Convention on Biological Diversity. Canada's overseas development assistance has decreased from $5 billion to $2 billion in the last decade. The proportion of this assistance allocated for the environment is about 10%. Family-planning support, which has declined to about $20 million from $50 million annually, should be increased along with a substantive program to raise the status, education, and empowerment of women. Appropriate investments in biodiversity conservation in other nations would also help to sustain ecological functions and services of the ecosphere we share, ensure an increased variety of bio-products in the future, and foster the development of potential green economies and markets for Canada.

Support to other nations is particularly needed for baseline biodiversity inventories, biosystematics and ecological studies, biodiversity data bases, and publication of professional and popular natural science manuals and atlases. Such expenditures will also help save innumerable species and unique ecosystems from extinction.

Canada should increase its international aid budget to the poorer nations and insist that part of this aid be allocated for biodiversity conservation projects and programs. Most nations in the lower latitudes are homes for "megadiversity", but they cannot afford to finance important biodiversity conservation efforts as intended under the Convention on Biological Diversity. We suggest that Canada's target for the year 2000 should be 1% of GNP. Developed nations have had a target of 0.7% for many years, although many never reached that amount. The 1% aid figure was recommended to Parliament in a report to the Standing Committee on Environment of the Canadian House of Commons (MacDonald 1993). As well, one Scandinavian country has set its international assistance at 1%. The overriding rationale is that the bulk of the world's remaining biodiversity is found in these countries and they need whatever help they can get.

7.3 CANADA'S UNMET NEEDS

This section provides a preliminary indication of the types of needs that the authors believe require further consideration and funding. While neither exhaustive, nor precisely costed, this information indicates particular areas where more effort is required. There is no implication of federal, provincial, or territorial government requirement to fund such needs; rather, these are raised as initial points for discussion among various levels of Canadian governments and other concerned parties such as environmental NGOs and industry groups. More discussion and consultation needs to be carried out before a more complete list of unmet needs can be realistically created. The time allowed for the production of this study did not permit for such consultations.

Canada's Green Plan provided the policy and program guidelines for major new initiatives in the entire environmental field. While the Plan had implications beyond biodiversity conservation, some of its policies and programs should positively effect Canada's biodiversity. The gross budget for Green Plan expenditures over the period 1991 through 1996 was approximately $3.0 billion (later cut back), broken down by component as follows:

• Clean Air, Water and Land	850,000,000
• Sustaining Renewable Resources	350,000,000
• Special Spaces and Species	175,000,000
• Arctic Stewardship	100,000,000
• Global Environmental Security	575,000,000
• Environmentally Responsible Decision-making	500,000,000
• Environmental Assessments and Audits	275,000,000
• Emergency Preparedness	175,000,000

But in 1995 the Green Plan was terminated.

Unmet needs have been grouped generally into two categories: 1) expansions to existing programs and activities; and 2) new programs and activities. The following summarizes the needs currently not being met to the desired level and estimates of the associated costs.[1] Footnote on page 152

7.3.1 EXPANSIONS TO EXISTING PROGRAMS AND ACTIVITIES

Three areas of expansion to existing programs are described below: education and training, research, and applications of knowledge. Within each area a number of programs are suggested. These are briefly described and a cost estimate is provided which is only approximate but gives an order of magnitude for the anticipated expenditures.

A. Education and Training

Education and training needs include components at the grade school, university, and general public levels.

a) Environmental education at school level (interpretation programs, teacher education, teaching resources, access to interpretive programs, etc.).
Estimated Cost: $162.5 million

b) Professionals and technicians in:

i. Ecology, taxonomy, genetics
Estimated cost: $16.5 million

ii. Resource management (agriculture, fisheries, forestry, parks)
Estimated cost: $13.5 million

iii. Biotechnology, plant breeding, organic chemistry
Estimated cost: $13.5 million

iv. Economics (natural resource, environmental, socio-economics)
Estimated cost: $9.0 million

v. Environmental law
Estimated cost: $4.5 million

vi. Engineering, commerce and other political and social sciences (courses integrated into these programs)
Estimated cost: $2.5 million annually

While not included in these calculations, there will be a need for education and training in other support disciplines such as computer programming, systems analysis, accounting, and others.

c) Training (seminars and workshops) in industry and government
Estimated cost: self-funding

d) Retraining in ecological principles and sustainable concepts in renewable resource management
Estimated cost: $0.75 million annually

B. Research

a) Strengthening of existing key research and researchers in biodiversity (biosystematics, ecology, conservation biology, sustainable resource management).
Estimated cost: $10 million

b) Research on the elimination of persistent toxic wastes (no production and/or recovery/recycling)

Estimated cost: *$50 million over 5 years*

c) Expanded natural history museums program (increased budget for federal program, increased assistance for provincial museums, museums for the two territories and establishment of one in Quebec)

Estimated cost: *$80 million*

d) Expanded university and government ecology staffs and research budgets

Estimated cost: *$65 million*

C. Applications of Knowledge

a) Programs aimed at sustainable agriculture, fisheries, forestry, wildlife and environmentally sound industry and municipalities:

- invention and application of research
- transfer of research to renewable resource and other fields
- biological control research
- changing government management plans for renewable resource management.

Estimated cost: *$180 million each year for 5 years*

b) Broadening of the scope of environmental impact assessments to include biodiversity considerations such as ecosystem functions and values and species and taxonomic diversity.

Estimated cost: *$1 million each year for 5 years*

c) Increased support for gene/species banks

Estimated cost: *10% increase over present budgets*

d) Species Recovery Programs: increase the biodiversity breadth of coverage

Estimated cost: *$10 million/year for 5 years*

e) CITES and COSEWIC programs: funding for additional studies in a greater variety of taxa and for endangered spaces for COSEWIC and increased CITES program management and operations.

Estimated cost: *25% increase over present budgets*

f) Increased funding to accelerate implementation of ecosystem programs in Green Plan for such activities as land and coastal use planning, creation of protected areas and restoration efforts.

Estimated cost: *$5 million*

g) Continued development, activating and monitoring a new national accounts system that recognizes changing natural resources stocks and environmental parameters.

Estimated cost: *$10 million (plus $1 million/year for 5 years.)*

h) Climate change and global warming: to be addressed in the Canadian position on protocols for that Convention.

i) Strengthening of databases on regional distribution of species/ecosystems diversity (BIODIV)

Estimated cost: *$5 million/year for 5 years.*

7.3.2 NEW PROGRAMS AND ACTIVITIES

a) New research activities concerned with biodiversity, by all professional disciplines identified in 1.A (above); including all required associated support (equipment, field costs, technicians, etc.)

Estimated cost: *$137.2 million*

b) Land/water/seascape acquisition by provinces for biodiversity reserves, parks, and protected areas, plus a new innovative/flexible National Parks policy to accommodate changing needs of society and "protection" of remaining 88%.

Estimated cost: $100 million/ year for 5 years.

c) Ecosystem functions research (input/output systems analysis) and taxonomic research (relationships between species) emphasizing gaps in our knowledge.

Estimated cost: $10 million/ year for 5 years.

d) International environmental assistance/contingency funds to protect Canada's long-term interests in global biodiversity, preserve Canada's biotechnology options, and help ensure global environmental security.

Estimated cost: $100 million/ year for 5 years.

e) Ecosystem rehabilitation (grasslands, Carolinian forests, heavily trawled fishing banks, and small scale ecosystems) linked to species rehabilitation.

Estimated cost: $20 million/ year for 5 years.

f) Encourage joint ventures, initiatives, and linkages of increased partnerships between government, industry, NGOs, native peoples, and others.

Estimated cost: $1 million/ year for 5 years.

g) Use of Canadian military personnel for peaceful purposes in environmental emergencies, protection/restoration projects.

Estimated cost: $5 million contingency fund

h) Prevention of species introductions: education, exotic watch system, action teams, policy development and regulation, and research.

Estimated cost: $3 million/ year for 5 years.

These estimated amounts total $2,753 million (exclusive of the Green Plan funds), for a five-year period. As noted at the start of this section, these figures are preliminary estimates prepared by the authors and do not reflect a consensus of concerned environmental and other organizations.

These figures, combined with the Green Plan Funds, estimate the total cost of Canada's unmet needs at $5.9 billion—less than $2 billion per year on environmental security. For purposes of comparison Canada has been spending about $12 billion per year on military security.

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[1] The assumptions on which these costs are based are contained in Appendix 14.

APPENDIX 1: CENSUS OF CANADA'S TAXONOMIC BIODIVERSITY

KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCRIBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CANADIAN SPECIES STILL UNRECORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN:			EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
				TERRESTRIAL	FRESH WATER	MARINE		
VIRUS (not a Kingdom) (viruses)	50,000 (order of magnitude only)	200	150,000	33	33	34	• regulate abundance of micro-organisms and larger species • gene transfer between organisms	Bergey's 1983/89; Olofsson *et al.* 1991; Suttle *et al.* 1990; Contreras 1990
KINGDOM: PROCARYOTAE (Monera - bacteria)								
PHYLA (17): Methanocreatrices; Halophitic and Thermo- acidophilic Bacteria; Aphragma- bacteria; Spirochaetae; Thiopneutes; Anaerobic Phototrophic bacteria; Nitrogen-fixing Aerobic bacteria; Pseudomonads; Omnibacteria; Chemautotrophic bacteria; Myxobacteria; Fermenting bacteria; Aeroendospora; Micrococci; Actinobacteria	>100,000 (order of magnitude only)	2,000	20,000	50	25	25	• convert dissolved carbon into food for protozoa and icroinvertebrates • mineralize organic molecules incl. petroleum and toxics • nitrogen fixation • methylate mercury • oxidize sulphur • symbionts of animals and plants • see text for others	Dunbar 1985; Hauxhurst *et al.* 1981; Bergey's 1983/1989; Murray 1989; Phyla are according to Margulis and Schwartz 1988
Cyanobacteria (blue-green algae); Chloroxybacteria	1,700	400	800	15	65	20	• primary production • nitrogen fixation • oxygen production • symbionts in lichens	Pick 1990 (p.c.)

APPENDIX I: CENSUS OF CANADA'S TAXONOMIC BIODIVERSITY

KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCRIBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CANADIAN SPECIES STILL UNRECORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN:			EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
				TERRESTRIAL	FRESH WATER	MARINE		
KINGDOM: PROTOCTISTA								
CHLOROPHYTA (green algae)	7,000						• primary production • oxygen production • symbionts in lichens and in coelentrates • soil conditioners • food chains • harmony	Garberry *et al.* 1956; Hamilton 1990 (p.c.); Findlay 1990 (p.c.); Poulin 1990 (p.c.)
Desmids		700	100	10	90	0		
Others		1000	200	10	80	10		
XANTHOPHYTA (yellow-green algae)		300	270	0	98	2	• primary production • oxygen production	Findlay 1990 (p.c.); Findlay and King 1979.
CHRYSOPHYTA (chrysophytes)	12,500	300	300	0	98	2	• primary production • major marine CO_2 ooze and plate formers (CO_2 sinks)	Hamilton 1990 (p.c.); Findlay 1990 (p.c.)
CHAROPHYTA (charas)		50	10	0	100	0	• primary production • oxygen production • freshwater CO_2 sinks • create 3-D lake-bottom ecosystem structure (unique habitat for aquatic insects, fish fry, etc.)	Hamilton 1990 (p.c.); Poulin 1990 (p.c.)
CRYPTOPHYTA (chryptophytes)	50	10	0?	0	100	0	• primary production • oxygen production • secondary detritivory (i.e. • they have "gullets"	
EUGLENOPHYTA (euglenas)	800	83 (Great Lakes only)	?	25?	60?	15?	• primary production • oxygen production	Hamilton 1990 (p.c.); Prescott 1962
BACILLARIOPHYTA (diatoms)		2000	750	10	45	45	• primary production • oxygen production • harmony	Findlay 1990 (p.c.); Findlay and King 1979; Bird 1990 (p.c.)

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				TERRESTRIAL	FRESH WATER	MARINE		
DINOPHYTA (dinoflagellates)		60	200	0?	100?	0?	• primary production • oxygen production • secondary detritivory (i.e. they have "gullets"	Findlay 1990 (p.c.); Findlay and King 1979
PHAEOPHYTA (brown algae)	1,500	300	100	0	20	80	• primary production • secondary production • creation of major 3-D • ecosystem structures in marine coastal waters	Garberry *et al.* 1956; Findlay 1990 (p.c.); Scagel 1967; Lee 1973
RHODOPHYTA (red algae)	4,000	500	50	1	1	98	• (similar to brown algae) • nesting material for cormorants	Garberry *et al.* 1956; Scagel 1967; South and Titl. 1986 South *et al.* 1988
"PROTOZOA" (many phyla acc. to Margulis and Schwartz 1988)	30,800	1000[b]	1000[b]	10?	45?	45?	• herbivory on phytoplankton • carnivory on zooplankton and bacteria • detritivory • major bases of food chains • CO_2 sinks (create most of the world's marine limestone) • food chains	Estimate for Canada by Ted Mosquin (no taxonomic information available for Canadian species)

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KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCRIBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CANADIAN SPECIES STILL UNRECORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN:			EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
				TERRESTRIAL	FRESH WATER	MARINE		
KINGDOM: EUMYCOTA (FUNGI)								
	1,500,000 (estimate for undescribed species' total)						• primary detritivory on dead microorgansisms, plants and animals • major mycorrhizal associations with most higher plants (the associations foster nutrient transfer for growth and survival of trees and other plants) • food for some insects, wildlife and humans • major soil conditioners • major nutrient transfer along • hyphae in soils • fermentation • moderate population explosions • major recyclers of carbon (decomposition) • symbiotic anaerobes in rumens of herbivores (Chytrids)	Hawksworth 1992.
MASTIGOMYCOTA (zoosporic fungi)		500	166	30	60	10		Can. Encycl. 1985; Hawksworth 1992; Redhead 1990 (p.c.); Barr 1993 (p.c.)
CHYTRIDIOMYCOTA (chytrids)	1,200	100	100	50	45	5		Barr, 1989; Barr, 1993 (p.c.)
ZYGOMYCOTA (zygomycete fungi)	665 ??	800	266	90	10	<1		Can. Encycl. 1985; Hawksworth 1992; Redhead 1990 (p.c.)
ASCOMYCOTA (cup fungi, morels)	10,650	5,000	1,666	90	10	<1		Can. Encycl. 1985; Hawksworth 1992; Redhead 1990 (p.c.)
BASIDIOMYCOTA (mushrooms, boletes, rusts, smuts)	16,000	3,400	1,133	95	5	0		Can. Encycl. 1985 Hawksworth 1992; Redhead 1990 (p.c.); Ginns 1992 (p.c.); Seifert 1992
LYCHENOPHYTA (lichen fungi)	16,000	2,000	500	100	0	0		Gowan and Brodo 1988; Brodo 1985; Egan 1987; Brodo 1992 (p.c.)

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				TERRESTRIAL	FRESH WATER	MARINE		
KINGDOM: PLANTAE								
BRYOPHYTA (mosses and liverworts)	16,600	965	50	98	2	0	• primary production • major microhabitat for micro fflora and fauna • major CO_2 sink (peat production) • moderate runoff	Ireland 1990 (p.c.); Ireland *et al.* 1987
LYCOPODIOPHYTA (club mosses)	1,275	32	1	100	0	0	• primary production • oxygen production • 3-D habitat for animal life	Beitel 1979; Cody and Britton 1989
EQUISETOPHYTA (horsetails)	15	10	0	90	10	0	• primary production • oxygen production • 3-D habitat for animal life • harmony	Cody and Britton 1989
PTERIDOPHYTA (ferns)	10,000	99	10	95	5	0	• primary production • oxygen production • 3-D habitat for animal life • harmony	Cody and Britton 1989
PINOPHYTA (or CONIFEROPHYTA) (conifers and kin)	529	34	0	100	0	0	• primary production • major 3-D ecosystem structure affecting all species in ecosystem • natural beauty • carbon dioxide sinks • moderate runoff • harmony	Hosie 1979; Scoggan 1978/79

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				TERRESTRIAL	FRESH WATER	MARINE		
MAGNOLIOPHYTA Dicots (native): 2050 Monocots (native): 930 + Dicots and monocots introduced): 884	220,000	3,864 2,050 930 884	75^b	85	15	<1	• primary production • oxygen production • major 3-D ecosystem structure for thousands of other species • great natural beauty (as a function of ecosystems) • many other functions • harmony	Scoggan 1979/79; Boivin 1967/68; Argus and Pryer
KINGDOM: ANIMALIA								
PORIFERA (sponges)	5,000 (all groups)						• herbivory and carnivory on phyto and zooplankton • primary detritivory • secondary detritivory • water filtration • creation of major 3-D ecosystem structures on ocean floor (habitat for fish and other benthic organisms • silicon and calcium recycling • harmony	Austin 1985; Reiswig 1990 (p.c.)
Calcarea (calcareous sponges)		60	60	0	0	100		
Desmospongeae		400	400	0	2	98		
Hexactinellida (silicious sponges)		30	20	0	0	100		

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				TERRESTRIAL	FRESH WATER	MARINE		
COELENTRATRATA (CNIDARIA) (coelentrates)	9,000 (all groups)						• primary and secondary carnivory	Shih *et al.* 1971; Arai and Brinkman /Voss 1980; Fraser 1944; Powell 1968; Calder 1990 (p.c.)
Anthozoa (sea anemones and corals)		90	75	0	0	100	• bases of numerous food chains • major CO_2 sinks (coral reefs in more tropical countries)	
Hydrozoa (hydras and medusas)		480	250	0	5	95	• symbiotic co-evolutionary partnerships with uni-cellular algae	
Scyphozoa (jellyfishes)		35	10	0	0	100		
CTENOPHORA (combjellies)	100	13	40	0	0	100	• primary and secondary carnivores (pelagic) • symbiosis (bioluminescence)	Shih *et al.* 1971; Calder 1990 (p.c.)
PLATYHELMINTHES (flat worms)	12,200 (all groups)						• carnivorous parasitism on invertebrates and vertebrates;	
Trematoda (flukes)		208[c]	187[c]	33 ?	33 ?	34	• turbellarians are mainly free living carnivores	Parker 1982; Laubitz *et al.* 1983
Turbellaria (planarians)		264[c]	237[c]	04	48	48		
NEMERTEA (ribbon worms)	?	132[c]	119[c]	5	15	80	• interstitial and sublittoral • carnivory	Parker 1982; Laubitz *et al.* 1983
GASTROTRICHA (gastrotrichs)	?	28[c]	25[c]	0	0	100	• carnivory	Parker 1982; Laubitz *et al.* 1983
ROTIFERA (rotifers)		500	175	5	90	5	• carnivory	Parker 1982; Changalath 1984; 1992 (p.c.)
KINORHYNCHA (kinorhynchs)		16[c]	14[c]	0	0	100	• herbivory on diatoms	Parker 1982; Laubitz *et al.* 1983.
NEMATA (roundworms)	12,000	1,000	200	25	25	50	• herbivory • carnivory (as parasites)	Parker 1982; Ebsary 1990 (p.c.)

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				TERRESTRIAL	FRESH WATER	MARINE		
NEMATOMORPHA (horsehair worms)		4	1	0	80	20	• parasitic on arthropods	Parker 1982; Ebsary 1990 (p.c.)
ACANTHOCEPHALA (thorny-headed worms)		25^c	22^c	10	70	20	• parasitic on fish, birds, amphibians, reptiles and mammals	Parker 1982; Laubitz *et al.* 1983
PRIAPULIDA (priapulid worms)		8^c	7^c	0	0	100	• rare; hypersaline muds and fine sediments • herbivory and carnivory	Parker 1982; Laubitz *et al.* 1983
MOLLUSCA (molluscs)	110,000 (all groups)							
Aplacophora		12	5	0	0	100	• hervivory and carnivory (i.e. as filter feeders) • secondary detritivory • direct herbivory • parasitism • bioturbation • major food for carnivores	Austin 1985; LaRoque 1953; Clarke 1981; Topping 1990 (p.c.); Stephen and Laubitz 1988
Gastropoda (snails)		869	75	20	40	40		
Bivalvia (clams and mussels)		490	30	0	10	90		
Polyplacophora (chitons)		38	3	0	0	100		
Scaphopoda (toothshells)		11	2	0	0	100		
Cephalopoda (squids and octopus)		80	20	0	0	100		
ANNELIDA (annelid worms)	12,000 (all groups)							
Archianelida		12	5	0	0	100	• parasitism (interstitial)	Madill 1985; Hobson and Banse 1981
Hirudinea (leeches)		70	5	0	66	34	• primary and secondary carnivory • parastism on aquatic animals	Madill 1985

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				TERRESTRIAL	FRESH WATER	MARINE		
Polychaeta (polychaete worms)		700	500	0	<1	99.8	• primary and secondary carnivory • sediment bioturbation (i.e. perform the same function as earthworms) • ubiquitous in marine environments	Hobson and Banse 1981; Banse and Hobson 1974; Pocklington 1980 Fournier and Levings 1982
Oligochaeta (earthworms)		200	160	25	50	25	• secondary detritivory • primary and secondary carnivory • soil aeration and drainage • sediment bioturbation	Reynolds 1977; Brinkhurst 1986
POGONOPHORA (beard worms)		16^c	14^c	0	0	100	• primary detritivory (i.e. absorb organic molecules directly through skin)	Parker 1982; Laubitz *et al.* 1983
VESTIMENTIFERA		2	8	0	0	100	• primary detritivory • symbiosis (with sulpher metabolizing bacteria (Juan de Fuca vents and deeps)	Jones 1990 (p.c.)
ECHIURA (spoon worms)	135	24^c	21^c	0	0	100	• secondary detritivory	Brusca and Brusca 1990; Parker 1982; Laubitz *et al.* 1983
SIPUNCULA (peanut worms)	250	36^c	30^c	0	0	100	• secondary detritivory • sediment bioturbation (probably)	Brusca and Brusca 1990; Parker 1982; Laubitz *et al.* 1983
MERISTOMATA (horseshoe crabs)		1	0	0	0	100	• secondary detritivory	?

APPENDIX 1: CENSUS OF CANADA'S TAXONOMIC BIODIVERSITY

KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCRIBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CANADIAN SPECIES STILL UNRECORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN:			EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
				TERRESTRIAL	FRESH WATER	MARINE		
ARACHNIDA								
Ascari (mites and ticks)		1,915	7,567	99	1	<1	• carnivory • fungivory • secondary detritivory • parasitism • major importance to food chains • numerous coevolutionary associations	Danks 1979; Danks 1988
Araneae (true spiders)		1,256	144	98	2	<1	• carnivory • moderate insect populations	Danks 1979; Danks 1988
Phalangida (daddy longlegs)		50	10	100	0	0	• carnivory	Dondale 1989 (p.c.)
Other Arachnids		54	10?	100 ?	0 ?	0 ?		Danks 1977; Danks 1988
DIPLURA		2	2	100	0	0	• carnivory??	Danks 1979
COLLEMBOLA (springtails)		295[a]	295[a]	100 ?	?	?	• fungivory • detritivory • herbivory	Danks 1979
PROTURA (proturans)		3	5	100	0	0	• secondary detritivory?	Danks 1979; 1988
TARDIGRADA (water bears)		50	150	50	40	10	• herbivory • carnivory	Danks 1979; Argus 1971; Argus 1972
PYCNOGONIDA (sea spiders)	1000 (all marine)	88[c]	80[c]	0	0	100	• parasitism (larvae) • carnivory (on sedentary coelentrates)	Brusca and Brusca 1990; Parker 1982; Laubitz *et al.* 1983

APPENDIX I: CENSUS OF CANADA'S TAXONOMIC BIODIVERSITY

KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCRIBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CANADIAN SPECIES STILL UNRECORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN: TERRESTRIAL	FRESH WATER	MARINE	EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
CRUSTACEA (gross underestimates - little is known about deep sea species)								
Branchiopoda (gill-footed shrimps)							• herbivory (on algae) • primary carnivory (on bacteria, protozoans, rotifers, etc.) • major food sources in freshwater and marine ecosystems	Rafi 1985; Laubitz and Rafi 1986; Changalath 1987; Laubitz 1992 (p.c.); Bousefield 1991 (p.c.)
Anacostraca		20	4	0	100	0		
Cladocera		145	30	0	98	2		
Conchostraca		9	1	0	100	0		
Notostraca		6	1	0	100	0		
Maxillopoda							• major primary and secondary carnivores • some parasitism on arthropods and vertebrates.	
Branchiura (fish lice)		10	3	50	50	0		
Copepoda (copepods)		825	250	0	40	60		
Cirrepedia (barnacles)		50	5	0	0	100		
Ostracoda (ostracods - bivalved crustaceans)		300	100	0	20	80	• filter feeders (i.e. herbivory, secondary detritivory and carnivory)	
Malacostraca (krill, lobster)							• filter feeders • parasitism • major components of marine food chains	
Leptostraca		3	1	0	9	91		
Amphipoda		1000	600	0	8	92		
Decapoda		300	60	3	9	88		
Isopoda		264[c]	238[c]	3	1	96		
Mysidacea		61	20	0	5	95		
Euphausiacea		19	17[c]	0	0	100		
Cumacea		71	30	0	0	100		
Tanaidacea		56[c]	51[c]	0	1	99		

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				TERRESTRIAL	FRESH WATER	MARINE		
INSECTA (possibly 30 million species on the Earth)								
Microphilia		3	10	100	0	0	• secondary detritivory?	Danks 1979; Danks 1988
Thysanura (silverfish)		2	10	100	0	0	• secondary detritivory	
Ephemeroptera (mayflies)		301	110	50	50	0	• detritivory and carnivory (larvae) • vital to freshwater food chains	
Odonata (dragonflies and damelflies)		194	3	50	50	0	• major carnivores (both nymphs and adults)	
Plecoptera (stoneflies)		250	60	50	50	0	• secondary detritivory • omnivory • carnivory • vital to freshwater food chains	
Dictuoptera (roaches and mantids)		17	6	100	0	0	• herbivory • carnivory	
Notoptera (grylloblattids)		2	3	100	0	0	• carnivory	
Dermaptera (earwigs)		5	0	100	0	0	• carnivory • herbivory	
Grylloptera (crickets and kin)		81	16	100	0	0	• herbivory • important food sources for terrestrial vertebrates	
Orthoptera (grasshoppers)		133	7	100	0	0	• herbivory • important in terrestrial food chains	
Cheleutoptera		1	1	100	0	0	• herbivory	
Psocoptera (book and bark lice)		72	31	100	0	0	• herbivory; • play key roles in microepiphyte • food chains	
Phthiraptera (lice)		362	413	100	0	0	• external parasitism, mainly on birds and mammals	

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KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCR-IBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CAN-ADIAN SPECIES STILL UNREC-ORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN:			EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
				TERR-ESTR-IAL	FRESH WATER	MARINE		
Hemiptera (true bugs)		3,079	1,147	100	0	0	• mainly herbivory (on plant juices) • major food sources for ants, • some bees and hummingbirds • some carnivory	
Thysanoptera (thrips)		102	144	100	0	0	• herbivory (plant juices and pollen)	
Megaloptera (alder flies)		16	5	100	0	0	• carnivory	
Raphidioptera (snake flies)		7	0				• carnivory	Danks 1979; Danks 1988
Neuroptera (lacewing flies)		75	14	100	0	0	• carnivory	
Coleoptera (beetles)		6,748	2,368	98	2	0	• herbivory • carnivory • decomposition • symbiosis (pollinators) • major food sources for birds	
Mecoptera (scorpion flies)		22	10	100	0	0	• secondary detritivory • some carnivory	
Diptera (flies and kin)		7,058	7,406	90	10	0	• herbivory • carnivory • secondary detritivory • critical to numerous food chains • vital pollinators • population moderation	

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KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCRIBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CANADIAN SPECIES STILL UNRECORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN:			EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
				TERRESTRIAL	FRESH WATER	MARINE		
Siphonaptera (fleas)		180	10	100	0	0	• parasites of birds and mammals	
Lepidoptera (butterflies moths and skippers)		4,629	2,042	100	0	0	• herbivory • essential components in numerous terrestrial food chains • population moderation	
Trichoptera (stone flies)		546	200	50	50	0	• herbivory • important in many freshwater food chains	
Hymenoptera (wasps, bees, and kin)		6,028	10,637	98 ?	2 ?	0	• herbivory; carnivory • many pollinators • major parasitism on insects (population moderation) • many coevolutionary associations	
CHILOPODA (centipedes)		70	35	100	0	0	• carnivory • secondary detritivory	
SYMPHYLA (symphylans)		2	10	100	0	0	• herbivory • soil conditioners (possibly)	
DIPLOPODA (millipedes)		64	35	100	0	0	• herbivory • secondary detritivory	
PAUROPODA		23	10	100	0	0	• detritivory (in soils)	
PENTASTOMIDA (tongue worms)		2	2	100	0	0	• parasitism in birds, reptiles, • mammals	Danks 1979; Danks 1988
PHORONIDA (horseshoe worms)		12[C]	11[C]	0	0	100	• ?	Laubitz *et al.* 1983

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KINGDOMS, MAJOR SUBDIVISIONS AND COMMON NAMES	GLOBAL TOTAL DESCR-IBED SPECIES	EST. NO. CANADIAN SPECIES REPORTED TO DATE	EST. CAN-ADIAN SPECIES STILL UNREC-ORDED	PRINCIPAL SECTORAL ECOSYSTEM — % OF SPECIES IN:			EXAMPLES OF ECOLOGICAL FUNCTIONS IN NATURAL ECOSYSTEMS AND/OR GLOBAL ECOSPHERE ("ECOSERVICES")	REFERENCES (MAINLY TAXONOMIC)
				TERR-ESTR-IAL	FRESH WATER	MARINE		
BRYOZOA (moss animals)							• secondary detritivory	Laubitz 1983
Gymnolaemata		580[C]	482[C]	0	2	98	• secondary carnivory and herbivory (i.e. filter feeders)	
Phyloctolaemata		24[C]	22[C]	0	0	100		
ENTOPROCTA (entoprocts)		32[C]	29[C]	0	0	100	• probably secondary detritivory	Laubitz 1983
BRACHIOPODA (lamp shells)		80[C]	72[C]	0	0	100	• benthic filter feeders	Laubitz 1983
CHAETOGNATHA (arrow worms)		12[C]	11[C]	0	0	100	• carnivory (mostly on copepods) • major base for oceanic food chains	Laubitz 1983
ECHINODERMATA							• primary and secondary carnivory • secondary detritivory • many suspension feeders • beauty	Grainger 1966; Austin 1985; Laubitz *et al.* 1983; Lambert 1989 (p.c.)
Asteroidea (starfishes)		50	10	0	0	100		
Echinoidea (sea urchins)		48[C]	42[C]	0	0	100		
Holotheuroidea (sea cucumbers)		84	18	0	0	100		
Crinoidea (sea lilies)		40[C]	36[C]	0	0	100		
Ophiuroidea (brittle stars)		160[C]	144[C]	0	0	100		
HEMICHORDATA (acorn worms)		16[C]	14[C]	0	0	100	• secondary detritivory (littoral sand to ocean depths)	Laubitz *et al.* 1983; Parker 1982; Bertin 1968

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				TERRESTRIAL	FRESH WATER	MARINE		
CHORDATA (Tunicata) (tunicates)							• (littoral sand to ocean depths)	
Appendicularia (appendicularians)		12^{C}	11^{C}	0	0	100	• pelagic detritivores • sedentary detritivores	Laubitz *et al.* 1983; Austin 1985
Ascidiacea (ascidians)		316^{C}	284^{C}	0	0	100		
Thaliacea (pelagic tunicates or salps)		24^{C}	22^{C}	0	0	100		
CHORDATA (Cephalo-chordata) (lancelets)		1?						
CHORDATA (Vertebrates)								
Agnatha (lampreys and hagfishes)		14	3	0	79	21	• primary and secondary carnivory	McAllister 1985; McAllister 1990; McAllister 1992
Chondrichthyes (sharks and kin)		56	10	0	0	100	• primary and secondary carnivory	
Osteichthyes (bony fishes)		1,021	500	0	20	80	• herbivory • carnivory • decomposition • major food groups for fishes, birds,mammals, detritivores and parasites	
Amphibia (frogs, (salamanders and kin)		42	2	80	20	0	• herbivory (tadpoles) • primary and secondary carnivory • communication	Cook 1984; Schueler 1992 (p.c.)
Reptilia (snakes, turtles)		42	0	90	5	5	• carnivory • food webs	Cook 1984

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				TERRESTRIAL	FRESH WATER	MARINE		
Aves (birds)	7,000	426	0 ?	95	3	2	• herbivory • carnivory • detritivory • major food sources for many vertebrates • pollination • seed dissemination • communication • harmony	Godfrey 1986; Ouellet 1990 (p.c.)
Mammalia (mammals)	?	194	0?	80	5	5	• herbivory • primary and secondary carnivory • decomposition • seed dissemination • major food sources for other vertebrates • communication • harmony	Banfield 1974; van Zyll de Jong 1983; van Zyll de Jong 1988
TOTALS (EXCLUDING VIRUSES)		71,109	68,377					
TOTALS (INCLUDING VIRUSES)		71,309	218,377					

GRAND TOTAL OF RECORDED AND UNRECORDED SPECIES (EXCLUDING VIRUSES) = 139,486

GRAND TOTAL OF RECORDED AND UNRECORDED SPECIES (INCLUDING VIRUSES) = 289,686

Notes:

a = estimates by Danks (1979, 1988) are very approximate

b = estimates by T. Mosquin based on global figures and/or geographical considerations

c = total described species is based upon number of genera (including synonyms) known from Canada based on Laubitz *et al.* (1983) multiplied by 4; total estimated undescribed species based on Laubitz *et al.* (1983) = total genera x 4 x 90%.

p.c. = personal communication

APPENDIX 2: Canadian species that are extinct, extirpated, threatened or vulnerable according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Subspecies and distinctive populations as treated as species. COSEWIC is concerned with the Canadian status of these groups, whether or not they occur outside of Canada (1994 data).

PLANTS	BIRDS	FISH	MARINE MAMMALS	REPTILES & AMPHIBIANS	MAMMALS
(i) EXTINCT SPECIES					
	• Passenger Pigeon *Ectopistes migratorius* • Great Auk *Pinguinis impennis* • Labrador Duck *Camptorhynchus labradorius*	• Banff Longnose Dace *Rhinichythys cataractae smithi* • Blue Walleye *Stizostedion vitreum glaucum* • Deepwater Cisco *Coregonus johannae* • Longjaw Cisco *Coregonus alpenae*	• Sea Mink *Mustela macrodon*		• Woodland Caribou (Dawson herd) *Rangifer tarandus dawsoni*
(ii) EXTIRPATED SPECIES					
• Blue-eyed Mary *Collinsia verna* • Illinois Tick Trefoil *Desmodium illinoense*	• Greater Prairie Chicken *Tympanuchus cupido pinnatus*	• Gravel Chub *Hybopsis x-punctata* • Paddlefish *Poyodon spathula*	• Gray Whale (Atlantic pop.) *Eschrichtius robustus* • Walrus (N.W.Atlantic pop.) *Odobenus rosmarus*		• Black-Footed Ferret *Mustela nigripes* • Plains Grizzly Bear *Ursus aretos* • Swift Fox *Vulpes velox*

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PLANTS	BIRDS	FISH	MARINE MAMMALS	REPTILES & AMPHIBIANS	MAMMALS
(iii) ENDANGERED SPECIES					
• Cucumber Tree *Magnolia acuminata* • Eastern Mountain Avens *Geum peckii* • Eastern Prickly Pear Cactus *Opuntia humifusa* • Furbish's Lousewort *Pedicularis furbishiae* • Gattinger's Agalinis *Agalinis gattingeri* • Heart-leaved Plantain *Plantago cordata* • Hoary Mountain Mint *Pycnanthemum incanum* • Large Whorled Pogonia *Isotria verticillata* • Pink Coreopsis *Coreopsis rosea* • Pink Milkwort *Polygala incarnata* • Skinner's Agalanis *Agalanis skinneriana* • Slender Bush Clover *Lespedeza virginica* • Small White Lady's Slipper *Cypripedium candidum* • Small Whorled Pogonia *Isotria medeoloides* • Southern Maidenhair Fern *Adiantum capillus-veneris*	• Eskimo Curlew *Numenius borealis* • Harlequin Duck (eastern pop.) *Histrionicus histrionicus* • Kirtland's Warbler *Dendroica kirtlandii* • Loggerhead Shrike (eastern pop.) *Lanius ludovicianus migrans* • Mountain Plover *Charadrius montanus* • Peregrine Falcon (anatum) *Falco peregrinus anatum* • Piping Plover *Charadrius melodus* • Whooping Crane *Grus americana* • Northern Bobwhite *Colinus virginianus* • Acadian Flycatcher *Empidonax virescens* • Spotted Owl *Strix occidentalis* • King Rail *Rallus elegans* • Henslow's Sparrow *Ammodramus henslowii* • Sage Thrasher *Oreoscopies montana*	• Acadian Whitefish *Coregonus huntsmani* • Aurora Trout *Salvelinus fontinalis* • Salish Sucker *Catostomus* sp.	• Beluga Whale (St.Lawrence pop.) *Delphinapterus leucas* • Beluga Whale (Ungava Bay pop.) *Delphinapterus leucas* • Beluga Whale (S.E. Baffin Is. pop.) *Delphinapterus leucas* • Bowhead Whale *Balaena musculus* • Right Whale *Eubalaena glacialis* • Sea Otter *Enhydra lutris*	• Blanchard's Cricket Frog *Acris crepitans blanchardi* • Blue Racer *Coluber constictor foxii* • Lake Erie Water Snake *Nerosia sipedon insularum* • Leatherback Turtle *Dermochelys coriacea*	• Eastern Cougar *Felis concolor couguar* • Peary Caribou (Banks Is. pop.) *Rangifer tarandus pearyi* • Peary Caribou (High Arctic pop.) *Rangifer tarandus pearyi* • Vancouver Island Marmot *Marmota vancouverensis* • Wolverine (eastern pop.) *Gulo gulo*

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PLANTS	BIRDS	FISH	MARINE MAMMALS	REPTILES & AMPHIBIANS	MAMMALS
(iii) ENDANGERED SPECIES (continued)					
• Slender Mouse-eared Cress *Halimolobos virgata* • Western Fringed Prairie Orchid *Platanthera praeclara* • Wood Poppy *Stylophorum diphyllum* • Engelmann's Quillwort *Isoetes engelmannii* • Spotted Wintergreen *Chimaphila maculata* • Thread-leaved Sundew *Drosera filiformis* • Water-pennywort *Hydrocotyle umbellata* • White Prairie Gentian *Gentiana alba*					

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PLANTS	BIRDS	FISH	MARINE MAMMALS	REPTILES & AMPHIBIANS	MAMMALS
(iv) THREATENED SPECIES					
• American Chesnut *Castanea dentata* • American Water-willow *Justicia americana* • Anticosti Aster *Aster anticostensis* • Bird's Foot Violet *Viola pedata* • Blue Ash *Fraxinus quadrangulata* • Bluehearts *Buchnera americana* • Colicroot *Aletris farinosa* • Giant Helliborine *Epipactus gigantea* • Ginseng *Panax quinquefolium* • Golden Crest *Lophiola aurea* • Golden Seal *Hydrastis canadensis* • Kentucky Coffee Tree *Gymnocladus dioica* • Mosquito Fern *Azolla mexicana* • Nodding Pogonia *Triphora trianthophora* • Beach Thistle *Cirsium pitcheri* • Plymouth Gentian *Sabatia kennedyana* • Purple Twayblade *Liparis liliifolia* • Red Mulberry *Morus rubra* • Sweet Pepperbush *Clethra alnifolia*	• Baird's Sparrow *Ammodramus bairdii* • Burrowing Owl *Athene cunicularia* • Ferriginous Hawk *Buteo regalis* • Loggerhead Shrike (prairie pop.) *Lanius ludovicianus* • Marbled Murrelet *Brachyramphus marmoratus* • Yellow-breasted Chat *Icteria virens auricollis* • Hooded Warbler *Wilsonia citrina* • White-headed Woodpecker *Picoides albolarvatus* • Roseate Tern *Sterna dougallii*	• Black Redhorse *Moxostoma duquesnei* • Blackfin Cisco *Coregonus nigripinnis* • Copper Redhorse *Moxostoma hubbsi* • Enos Lake Stickleback *Gasterosteus sp.* • Great Lakes Deepwater Sculpin *Myoxocephalus thompsoni* • Lake Simco Whitefish *Coregonus clupeaformis* • Margined Madtom *Noturus insignis* • Shorthead Sculpin *Cottus confusus* • Shortjaw Cisco *Coregonus zentihicus* • Shortnose Cisco *Coregonus reighardi* • Channel Darter *Percina copelandi* • Eastern Sand Darter *Ammocrypia pellucida*	• Beluga Whale (E.Hudson Bay pop.) *Delphinapterus leucas* • Harbour Porpoise (W.Atlantic pop.) *Phocoena phoceana* • Humpback Whale (N.Pacific pop.) *Megaptera novaeangliae*	• Eastern Massasauga Snake *Sistrurus catenatus catenatus* • Spiny Softshell *Apalone spinifera* • Eastern Massasauga Rattlesnake *Sistrurus catenatus catenatus*	• Newfoundland Pine Martin *Martes americana atrata* • Peary Caribou (Low Arctic pop.) *Rangifer tarandus pearyi* • Wood Bison *Bison bison athabascae* • Woodland Caribou (Maritime pop.) *Rangifer tarandus caribou* • Pacific Water Shrew *Sorex bendirii*

APPENDIX 2: Canadian species that are extinct, extirpated, threatened or vulnerable according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Subspecies and distinctive populations as treated as species. COSEWIC is concerned with the Canadian status of these groups, whether or not they occur outside of Canada (1994 data).

PLANTS	BIRDS	FISH	MARINE MAMMALS	REPTILES & AMPHIBIANS	MAMMALS
(iv) THREATENED SPECIES (continued)					
• Athabasca Thrift *Armeria maritima interior* • Tyrrell's Wollow *Salix planifolia tyrrellii* • Western Blue Flag *Iris missouriensis* • Bluehearts *Buchnera americana* • Deerberry *Vaccinium stamineum* • Round-leaved Greenbrier *Smilax rotundifolia* • van Brunt's Jacob's Ladder *Polemonium van-bruntiae* • Small-flowered Lipocarpha *Lipocarpha micrantha* • Redroot *Lachnanthes caroliana* • Western Spiderwort *Tradescantia occidentalis* • Sand Verbena *Abronia micrantha* • Blunt-lobed Woodsia *Woodsia obtusa*					

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(v) VULNERABLE SPECIES

PLANTS

- Broad Beech-fern *Phegopteris hexagonoptera*
- Dense Blazing Star *Liatris spicata*
- Dwarf Hackberry *Celtis tenuifolia*
- False Rue-Anemone *Isopyrum biternatum*
- Few-flowered Club-rush *Scirpus verecundus*
- Green Dragon *Arisaema dracontium*
- Gulf of St. Lawrence Aster *Aster laurentianus*
- Hill's Pondweed *Potamogeton hillii*
- Hop Tree *Ptelea trifoliata*
- Indian Plantain *Cacalia plantaginea*
- Lilaeopsis *Lilaeopsis chinesis*
- Macoun's Meadowfoam *Limnanthes macounii*
- Prairie Rose *Rosa setigera*
- Eastern Prairie White-fringed Orchid *Plantanthera leucophaea*
- Shumard Oak *Quercus shumardii*
- Soapweed *Yucca glauca*
- Swamp Rose Mallow *Hibiscus moscheutos*
- Victorin's Gentian *Gentiana victorinii*
- Victorin's Water-hemlock *Cicuta maculata victorini*

BIRDS

- Barn Owl *Tyto alba*
- Caspian Tern *Sterna caspia*
- Cooper's Hawk *Accipiter cooperii*
- Eastern Bluebird *Sialia sialis*
- Flammulated Owl *Otus flammeolus*
- Great Gray Owl *Strix nebulosa*
- Ipswich Sparrow *Passerculus sandwichenis princeps*
- Ivory Gull *Pagophila eburnea*
- Least Bittern *Ixobrychus exilis*
- Louisiana Waterthrush *Seiurus motacilla*
- Peale's Peregrine Falcon *Falco peregrinus pealei*
- Tundra Peregrine Falcon *Falco peregrinus tundrius*
- Prairie Warbler *Dendroica discolor*
- Prothonotary Warbler *Protonotaria citrea*
- Red-shouldered Hawk *Buteo lineatus*
- Ross' Gull *Rhodostethia rosea*
- Trumpeter Swan *Cygnus buccinator*
- Yellow-breasted Chat *Icteria virens virens*
- Long-billed Curlew *Numenius americanus*

FISH

- Banded Killifish (Nfld pop.) *Fundulus diaphanus*
- Bering Wolffish *Anarhichas orientalis*
- Bigmouth Buffalo *Ictiobus cyprinellus*
- Bigmouth Shiner *Notropis dorsalis*
- Black Buffalo *Ictiobus niger*
- Pubnose Shiner *Notropis anogenus*
- Rosyface Shiner *Notropis rubellus*
- Lake Chubsucker *Erimyzon succata*
- Spring Cisco *Coregonus artedi*
- Blackline Prickleback *Acantholumpenus mackayi*
- Blackstripe Topminnow *Fondulus notatus*
- Brindled Madtom *Noturus miurus*
- Central Stoneroller *Campostoma anomalum*
- Charlotte Unarmoured Stickleback *Gasterosteus aculeatus*
- Chestnut Lamprey *Ichthyomzon castaneus*
- Fourhorn Sculpin (Arctic Islands fresh water form) *Myoxocephalus quadricornis*
- Giant Stickleback *Gasterosteus sp.*
- Green Sturgeon *Acipenser medirostris*
- Greenside Darter *Etheostoma blennioides*
- Kiyi *Coregonus kiyi*

MARINE MAMMALS

- Blue Whale (Atlantic and Pacific populations.) *Balaenoptera musculus*
- Fin Whale (Atlantic and Pacific populations) *Balaenoptera physalus*
- Humpback Whale (Atlantic pop) *Megaptera novaeangliae*
- Sowerby's Beaked Whale (Atlantic Ocean pop.) *Mesoplodon bidens*
- Beluga Whale (eastern high Arctic pop.) *Delphinapterus leucas*

REPTILES & AMPHIBIANS

- Eastern Short-horned Lizard *Phrynosoma douglasii brevirostre*
- Eastern Yellowbelly Racer *Coluber constictor flaviventris*
- Fowler's Toad *Bufo Woodhousii fowleri*
- Northern Prairie Skink *Eumeces septentrionalis septentrionalis*
- Pacific Giant Salamander *Dicamptodon tennebrosus*
- Smallmouth Salamander *Ambystoma texanum*
- Spotted Turtle *Clemmys guttata*

MAMMALS

- Black-tailed Prairie Dog *Cynomys ludovicianis*
- Eastern Mole *Scalopus aquaticus*
- Fringed Myotis Bat *Myotis thysanodes*
- Gaspe Shrew *Sorex gaspensis*
- Spotted Bat *Euderma maculatum*
- Grey Fox *Urocyon cinereoargenteus*
- Grizzly Bear *Ursus arctos*
- Keen's Long-eared Bat *Myotis keenii*
- Pallid Bat *Antrozous pallidus*
- Plains Pocket Gopher *Geomys bursarius*
- Polar Bear *Ursus maritimus*
- Queen Charlotte Islands Ermine *Mustela erminea haidarum*
- Southern Flying Squirrel *Glaucomys volans*
- Wolverine (western pop.) *Gulo gulo*
- Woodland Caribou (western pop.) *Rangifer tarandus caribou*
- Nuttall's Cottontail Rabbit (Okanagan pop.) *Sylvilagus nuttallii*
- Western Harvest Mouse *Reithrodontomys megalotis*

APPENDIX 2: Canadian species that are extinct, extirpated, threatened or vulnerable according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Subspecies and distinctive populations as treated as species. COSEWIC is concerned with the Canadian status of these groups, whether or not they occur outside of Canada (1994 data).

PLANTS	BIRDS	FISH	MARINE MAMMALS	REPTILES & AMPHIBIANS	MAMMALS
(v) VULNERABLE SPECIES (continued)					
• Western Silver-leaf Aster *Virgulus sericeus* • Bathurst Aster *Aster subulatus, var. obtusifolius* • Branched Bartonia *Bartonia paniculata* • Long's Bullrush *Scirpus longii* • American Columbo *Frasera carolinensis* • Provancher's Fleabane *Erigernon philadelphicus, var. provancheri* • Smooth Goosefoot *Chenopodium subglabrum* • Wild Hyacinth *Camassia scilloides* • Phantom Orchid *Cephalanthera austinae* • Indian Plantain *Cacalia plataginea* • New Jersey Rush *Juncus caesariensis*	• Ancient Murrelet *Synthliboramphus antiquus* • Short-eared Owl *Aslo flammeus* • Cerulean Warbler *Dendroica discolor*	• Lake Lamprey *Lampetra macrostoma* • Northern Brook Lamprey *Ichthyomyzon fossor* • Orangespotted Sunfish *Lepomis humilis* • Pacific Sardine *Sardinops sagax* • Pugnose Minnow *Notropis emilae* • Pugnose Shiner *Notropis anogenus* • Redbreasted Sunfish *Lepomis auritus* • Orangespotted Sunfish *Lepomis humilis* • Warmouth *Lepomis gulosus* • Redside Dace *Clinostomus elongatus* • River Redhorse *Moxostoma carinatum* • Shortnose Sturgeon *Acipenser brevirostrum* • Silver Chub *Hybopsis storeiana* • Silver Shiner *Notropis photogenis* • Speckled Dace *Rhinichthys osculus* • Spotted Gar *Lepisosteus oculatus* • Spotted Sucker *Minytrema melanops* • Squanga Whitefish *Coregonus* sp. • Umatilla Dace *Rhinichthys umatilla* • White Sturgeon *Acipenser transmontanus*			

APPENDIX 3: HABITAT/ECOSYSTEM DIVERSITY AND ESTIMATED PERCENT CHANGE OVER THE PAST 250 YEARS

HABITAT/ECOSYSTEM	TOTAL AREA AND % OF COUNTRY	ESTIMATED AREA CONVERTED/MODIFIED	BIODIVERSITY FUNCTION / ROLE	REFERENCE
i) FORESTS	4,456,000 km^2 45%	• 90% Carolinian forest • Most of coastal B.C. old-growth • 30 to 60% of boreal forest	Table 2 and Chapter 4	Environment Canada 1991
ii) GRASSLANDS (Former prairie)	500,000 km^2 5%	• 90% rough fescue • 99% tall-grass • 80% short-grass • 75% mixed-grass • 80% aspen parkland	Table 2 and Chapter 4	Hummel 1989
iii) WETLANDS	1,244,000 km^2 14%	• 65% Atlantic coastal marshes • 70% southern Ont. • 90% southwest Ont. • 71% prairie • 80% Fraser River delta, B.C.	Table 2 and Chapter 4	Environment Canada 1991; Statistics Canada 1991a
iv) FRESHWATER	755,180 km^2 7.6%	n/a	Table 2 and Chapter 4	Shay 1981
v) MARINE (off shore)	6,500,000 km^2 243,000 km coastline	n/a	Table 2 and Chapter 4	
vi) CORAL REEFS	0	n/a	n/a	
viii) ARID/SEMI-ARID	Not estimated	Not known	Table 2 and Chapter 4	
ix) DESERTS	10 km^2 (est.)	90%	Table 2 and Chapter 4	
x) TUNDRA	2,303,000 km^2 23%	5% to 15%	Table 2 and Chapter 4	Environment Canada 1991

APPENDIX 4: AREAS OF HIGH PLANT SPECIES ENDEMISM

How many sites (and their sizes) in Canada may be considered areas of high species endemism in respect to plants and/or animals? Indicate below the value placed on these species.

PROVINCE/ TERRITORY	SITES	TOTAL AREA	NUMBER OF ENDEMIC SPECIES	BIODIVERSITY VALUE	REFERENCES
NEWFOUNDLAND	• none	n/a	n/a	n/a	Knox 1991 (p.c.)
PRINCE EDWARD ISLAND	NDR (no data received)	NDR	NDR	NDR	
NOVA SCOTIA	NDR	NDR	NDR	NDR	
NEW BRUNSWICK					
QUEBEC	NDR	NDR	NDR	NDR	
ONTARIO	• Windsor Prairie				
	• Lake Superior's north shore				
MANITOBA	NDR	NDR	NDR	NDR	
SASKATCHEWAN	• Athabasca sand dunes	NDR	NDR	NDR	WWF 1989
	• nothern boreal region				
ALBERTA	NDR	NDR	NDR	NDR	
BRITISH COLUMBIA	• Queen Charlotte Islands/northern Vancouver Island	• 8 300km^2	• 9		Eastman 1991 (p.c.); Douglas and Manning 1991
	• Coast-Cascade Mountains/Selkirk Mountains	• 150 000	• 1		
	• Rocky Mountains	• 66 000	• 9		
	• southern Vancouver Island/lower Fraser Valley	• 1 400	• 1		
	• north Pacific Coast	• 65 000	• 13		
	• northern Rocky Mountains	• 21 000	• 1		
	• southern Vancouver Island/Gulf Islands	• 700	• 1		
	• Canada-U.S. Cascade-Rocky Mountains	• 140 000	• 9		
	• Vancouver Island ranges/north Cascades	NDR	NDR		
	• northern Rocky Mountains	NDR	NDR		
	• Kluane ranges/northern Rocky mountains	NDR	NDR		
	• southern B.C.	NDR	NDR		
	• northern mountains and plateaus	NDR	NDR		
	• Vancouver Island ranges/Olympic Mountains	NDR	NDR		
	• northern Cascades	NDR	NDR		
	• Shuswap Highlands/Okanogan Valley/Columbia River basin	NDR	NDR		
	• northern Cordillera/ Aleutian Islands	NDR	NDR		
YUKON	Northern Yukon National Park	NDR	• 30?		Kennedy 1990
NORTHWEST TERRITORIES	none known				Lloyd 1991 (p.c.)
TOTAL					

APPENDIX 5: AREAS OF HIGH ANIMAL SPECIES ENDEMISM

Number of sites (and their sizes) in Canada known to be areas of high species endemism in respect to plants and/or animals.

PROVINCE/TERRITORY	SITES	TOTAL AREA	NUMBER OF ENDEMIC SPECIES	BIODIVERSITY VALUE	REFERENCES
NEWFOUNDLAND	• western Newfoundland mature boreal forest • Avalon Pennisula • Cape Shore • central Nfld. boreal forest	11200 km^2 11150 km^2 1250 km^2 160 km^2		protection of unique genetic resources	Knox 1991 (p.c.)
PRINCE EDWARD ISLAND				protection of unique genetic resources	
NOVA SCOTIA	southern Nova Scotia		Acadian whitefish	protection of unique genetic resources	
NEW BRUNSWICK				protection of unique genetic resources	
QUEBEC	Montreal area		Copper redhorse	protection of unique genetic resources	
ONTARIO & MANITOBA				protection of unique genetic resources	
SASKATCHEWAN				protection of unique genetic resources	
ALBERTA	Alberta (Jasper/Banff region)		1 isopod; 2 ampipods 2 gastropods; 1 fish	protection of unique genetic resources	
BRITISH COLUMBIA	• Enos, Cowichan Lakes; Nanaimo lowland • Texada Island; Strait of Georgia • Queen Charlotte Islands; windward Queen Charlotte Mountains • Graham Island; Queen Charlotte lowland • Louise Island; Skidgate plateau • Vancouver Island; Nahwitti lowlands • Brooks Peninsula; windward island mountains • Fraser Valley; Fraser lowlands	NDR NDR NDR NDR NDR NDR NDR NDR	18+ 12+ 14+ 11+ 11+ 11+ 1? 12+	protection of unique genetic resources	McPhail 1992; Beamish 1982; Kavanaugh 1979; Ferguson 1987; Moodie and Reimchen 1976; McPhail 1991 (p.c.); Cannings & Cannings 1992
YUKON	Richardson Mountains	NDR	Henlea (see text)	protection of unique genetic resources	Tynen 1991; Smith 1990.
NORTHWEST TERRITORIES	Arctic archipelago		3 molluscs	protection of unique genetic resources	Lloyd 1991 (p.c.); Topping 1990 (p.c.)

APPENDIX 6: NATIONAL PARKS/NATURE RESERVES/GAZETTED FORESTS (AS PER IUCN CATEGORIES) AND OTHER PROTECTED SITES

Total number, size and percentage of the total land area of Canada in respect of: (i) national parks/nature reserves/forests (as per IUCN categories); and (ii) biosphere reserves, Ramsar sites and World Heritage sites. Biodiversity value, role and/or function attatched to the respective *in situ* conservation areas.

IN SITU HABITAT/ECOSYSTEM	TOTAL NUMBER	TOTAL AREA	% OF TOTAL LAND AREA	BIODIVERSITY VALUE/ROLE/FUNCTION	REFERENCES
i) EXISTING PARKS/NATURE RESERVES	1,685	330,746 km^2	3.4%	• roles range from protection of ecosystems to protection of individual species	
ii) NEW/PROPOSED PARKS/RESERVES	Sask. committed to doubling current parks system				
iii) EXISTING BIOSPHERE RESERVES	6	4,481 km^2	0.05%	• protect a representation of one of the world's major ecological systems	
iv) NEW/PROPOSED BIOSPHERE RESERVES					
v) EXISTING RAMSAR SITES	30	130,000 km^2	1.3%	• protect wetlands of international significance	
vi) NEW/PROPOSED RAMSAR SITES					
vii) EXISITNG WORLD HERITAGE SITES (natural)	6	89,739 km^2	1.0%	• protect areas of internationally unique value	Cantin 1992 (p.c.)
viii) NEW/PROPOSED WORLD HERITAGE SITES					
ix) EXISTING GAZETTED FORESTS	n/a	n/a	n/a	n/a	
x) NEW/PROPOSED GAZETTED FORESTS	n/a	n/a	n/a	n/a	
xi) OTHERS (specify)					

APPENDIX 7: TERRESTRIAL ECOREGION AND MARINE REGIONS CURRENTLY NOT PROTECTED OR REPRESENTED IN THE PARKS/RESERVE SYSTEM OR SITES LISTED IN APPENDIX 6

Number of national biogeographic provinces or biotic communities in Canada. Number and size of those biogeographic provinces or biotic communities that are currently NOT protected or represented in the present network of parks/nature reserves/gazetted forests because of financial and other constaints.

BIOGEOGRAPHICAL PROVINCES	TOTAL NUMBER	UNREPRESENTED/ UNPROTECTED		% OF TOTAL AREA	BIODIVERSITY VALUE/ROLE/FUNCTION	REFERENCES
		NUMBER	SIZE			
i) NATIONAL TERRESTRIAL ECOREGIONS	177	45		undetermined	see Table 2 and Chapter 4	Turner *et al.* 1991
ii) NATIONAL MARINE REGIONS	29	27		undetermined	see Table 2 and Chapter 4	Canadian Environmental Advisory Council 1991

APPENDIX 8: PRIVATE WILDLIFE MANAGEMENT AREAS AND SANCTUARIES

Privately owned wildlife sanctuaries. Names and sizes including information regarding their biodiversity value/role/function.

AGENCY/NAME OF SANCTUARY	TOTAL AREA (km^2)	NUMBER OF ANIMAL SPECIES	NUMBER OF PLANT SPECIES	NUMBER OF ENDEMIC SPECIES	BIODIVERSITY FUNCTION	REFERENCES
DUCKS UNLIMITED	2,900,000 (under active management)	?	?	?	important for waterfowl and many species dependent upon managed wetlands	
NATURE CONSERVANCY	32,000 (sanctuaries)	?	?	?	to assist with the survival of integral natural ecosystems and assemblages of species that require such protected areas	
WILDLIFE HABITAT CANADA	15,000	?	?	?	to assist with the survival of integral natural ecosystems and assemblages of species that require such protected areas	
FEDERATION OF ONTARIO NATURALISTS • Dorcas Bay Nature Reserve • Petrel Point Nature Reserve • Malcolm Kirk Nature Reserve • George C. Newton Nature Reserve • Stone Road Alvar Nature Reserve • Harold Mitchell Nature Reserve • Wilfred G. Crozier Nature Reserve • Willoughby Nature Reserve • Altberg Wetland Candidate Nature Reserve • Altberg Southern Shield Nature Reserve • H.N. Crossley Nature Reserve • Stewartville Swamp Nature Reserve • St. Josephs Island Nature Reserve	530 (sanctuaries)	?	?	?	to assist with the survival of integral natural ecosystems and assemblages of species that require such protected areas	F.O.N.
SASKATCHEWAN NATURAL HISTORY SOCIETY • Hidden Valley • Dog Town + 2 others	129.5 ha. 32.4 ha. (sanctuaries)	?	?	?	to assist with the survival of integral natural ecosystems and assemblages of species that require such protected areas	Laing 1991 (p.c.)

APPENDIX 9: STATUS OF CANADIAN *EX SITU* CONSERVATION FACILITIES

KIND OF INSTITUTION	NUMBER OF INSTITUTIONS		TOTAL NUMBER OF SPECIES AND SPECIMENS			BIODIVERSITY VALUE	REFERENCES
	Existing	Required	Type	Species	Specimens		
Zoos/ Zoological Gardens	50		Mammals	200	9,000	Contribute to the survival of unique populations and species that are near extinction	CAZPA 1991; Canadian Museums Association 1990-91
			Birds	200	7,700		
			Reptiles	150	2,300		
			Amphibians	50	1,000		
			Fish	150	2,500		
			Invertebrates	70	5,500		
Aquaria	15		Mammals	30	100	Contribute to the survival of unique populations and species that are near extinction	CAZPA 1991; Canadian Museums Association 1990-91
			Birds	20	150		
			Reptiles	50	350		
			Amphibians	25	120		
			Fish	1,500	5,400		
			Invertebrates	300	1,700		
Aviaries	15		Mammals	50	150	Contribute to the survival of unique populations and species that are near extinction	CAZPA 1991; Canadian Museums Association 1990-91
			Birds	300	1,000		
			Reptiles	10	20		
			Fish	5	30		
Museums	100		Mammals	500	400,000	Principal repositories of specimens for future scientific study, data bases for conservation and management	Canadian Museums Association 1990-91
			Birds				
			Reptiles/ Amphibians	850	300,000		
			Fish	4,000	3,500,000		
			Invertebrates	40,000	>50,000,000		
Botanical Gardens/ Arboreta	60		Plants	40,000	>100 M	Temporary propagation of endangered plants	CAZPA 1991; Ray 1991; Holmgren *et al.* 1990; Boivin 1980

APPENDIX 9: STATUS OF CANADIAN *EX SITU* CONSERVATION FACILITIES

KIND OF INSTITUTION	NUMBER OF INSTITUTIONS		TOTAL NUMBER OF SPECIES AND SPECIMENS			BIODIVERSITY VALUE	REFERENCES
	Existing	Required	Type	Species	Specimens		
Herbaria	220		Plants	<100,000	7,000,000	Permanent documentation of occurrence of species	CAZPA 1991; Ray 1991; Holmgren et al. 1990; Boivin 1980
Germplasm/ Seed/ Gene Banks	30		Seeds/ Germplasm	2,000	150,000	Survival of unique genetic strains that might otherwise be lost	Agriculture Canada 1991a; Ray 1991; Weldon *et al.* 1986; Agriculture Canada 1991a; Petawawa Forestry Inst. (Info.)
Microbial Culture Collections	150		All Types	4,000	90,000	Survival of unique genetic strains that might otherwise be lost	Agriculture Canada 1991a; Weldon *et al.* 1986; Industry, Science, & Technology 1991; Agriculture Canada 1991b
			Type by % of total culture collections:				
			Bacteria		47%		
			Fungi		30%		
			Yeast		10%		
			Bacterial Viruses		6%		
			Mammalian Cells		2%		
			Animal Viruses		1%		
			Protozoa		1%		
			Algae		1%		
			Plant Viruses		0.5%		
			Amoebae		0.5%		
			Actinomycetes		0.5%		
			Helminths		0.5%		
			Insect Viruses		0.5%		
			Lichen		0.5%		

APPENDIX 9: STATUS OF CANADIAN *EX SITU* CONSERVATION FACILITIES

KIND OF INSTITUTION	NUMBER OF INSTITUTIONS	TOTAL NUMBER OF SPECIES AND SPECIMENS	BIODIVERSITY VALUE	REFERENCES
Data Banks	Total 185		Repositories of accumulating information on genes, species, ecosystems, ecological functions and habitat.	Canadian Nature Fed.; Royal Soc. Canada 1990; Environment Canada 1991; Statistics Canada 1991a; Statistics Canada 1990
	• Natural Heritage Program and Conservation Data Centre Network (CDCs)	3		
	• Department of Communications, Canadian Heritage Information Network (CHIN), Natural Science Databases	11 institutional		
	Collections	Management Databases		
	• Environment Canada	100		
	• Department of Fisheries and Oceans	35		
	• Forestry Canada;	10		
	• Canadian Museum of Nature	10		
	• Agriculture Canada	5		
	• Indian and Northern Affairs Canada	2		
	• Botanical Gardens Association Data Base	1		
	• Ontario Herpetofaunal Summary	1		
	• Quebec Herpetofaunal Summary	1		
	• Atlas of the Breeding Birds of Ontario	1		
	• Ontario Rare Breeding Bird Program;	1		
	• Maritimes Breeding Bird Atlas	1		
	• Atlas Saisonnier Des Oiseaux du Quebec	1		
	• Alberta Breeding Bird Atlas	1		
	• Canadian Association of Zoological Parks and Aquariums	1		
Others	?			

APPENDIX 10: ENDANGERED/RARE/VULNERABLE SPECIES IN CANADIAN *EX SITU* CONSERVATION FACILITIES

CATEGORY OF SPECIES PLANT/ANIMAL NATIVE/EXOTIC	TOTAL NUMBER OF SPECIES IN *EX SITU* FACILITIES	NUMBER OF SPECIES IN AN ACTIVE BREEDING PROGRAM	BIODIVERSITY VALUE/ROLE/ FUNCTION	REFERENCES
Native Plants	11 • Hop Tree *Ptelea trifoliata* • Red Bud (Extirpated in the wild) *Cercis canadensis* • Kentucky Coffee Tree *Gymnocladus dioica* • Blue Ash *Fraxinus quadrangulata* • American Chesnut *Castanea dentata* • Cucumber Tree *Magnolia acuminata* • Red Mulberry *Morus rubra* • Shumard Oak *Quercus shumardii* • Dwarf Hackberry *Celtis tenuifolia* • BeachThistle *Cirsium pitcheri* • Prairie Rose *Rosa setigera*	none	useful for possible re-introduction into future restored ecosystems; genetically unique populations, now extirpated, may survive in these facilities.	COSEWIC (1979-1994)

APPENDIX 10: ENDANGERED/RARE/VULNERABLE SPECIES IN CANADIAN *EX SITU* CONSERVATION FACILITIES

CATEGORY OF SPECIES PLANT/ANIMAL NATIVE/EXOTIC	TOTAL NUMBER OF SPECIES IN *EX SITU* FACILITIES	NUMBER OF SPECIES IN AN ACTIVE BREEDING PROGRAM	BIODIVERSITY VALUE/ROLE/ FUNCTION	REFERENCES
Native Animals	12 • Black Footed Ferret *Mustela nigripes* (Extirpated) • Swift Fox (Extirpated) *Vulpes velox* • Peregrin Falcon *Falco peregrinus anatum* • Wooping Crane *Grus americana* • Ferriginous Hawk *Buteo regalis* • Eastern Massassauga Snake *Sistrurus catenatus catenatus* • Wood Bison *Bison bison athabascae* • Great Grey Owl *Strix nebulosa* • Red Shouldered Hawk *Buteo lineatus* • Spotted Turtle *Clemmys guttata* • Grizzly Bear *Ursus arctos* • Polar Bear *Ursus maritimus*	5 • Black Footed Ferret (Extirpated) *Mustela nigripes* • Swift Fox (Extirpated) *Vulpes velox* • Peregrine Falcon *Falco peregrinus anatum* • Wooping Crane* *Grus americana* • Wood Bison* *Bison bison athabascae* * breeding program has been suspended at this time	short-term survival of unique and irreplaceable species and populations provide artificially reared animals for possible re-introduction programs	COSEWIC (1979-1994)
Exotic Plants	300	0	almost always negative	IUCN (Red Data Books)
Exotic Animals	100	60	almost always negative	CAZPA; IUCN

APPENDIX 11: WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCE
PLANTS (WILD)	• primary production	• food • building materials • energy • environmental health • shelter, food, and living places for wildlife species		• primary production • oxygen production (and ozone protection) • nutrient transfer • symbiosis • prime basis of terrestrial food chains	similar	Agriculture Canada 1991
Forest Trees	• commerce • subsistence • principal creators of 3-D ecosystem structures • food • shelter & living space for wildlife	• building materials • energy • recreation • watershed protection		• tree removal leads to forest thinning creating improved ungulate browse • intersectoral linkages generating income and employment • carbon sink • 3-D ecosystem structure for forest animals, birds, insects • watershed protection • environmental quality and health • climate moderation • food source for numerous organisms • soil conditioning	similar	Gailloux 1991 (p.c.); Statistics Can. 1990c; Statistics Can. 1990a
	• wood-hardwood lumber	• maple	38,000			Gailloux 1991 (p.c.)
		• birch	27,000			Gailloux 1991 (p.c.)
		• poplar, aspen, cottonwood	17,000			Gailloux 1991 (p.c.)
		• basswood	5,000			Gailloux 1991 (p.c.)
		• beech	3,000			Gailloux 1991 (p.c.)
		• oak	54,000			Gailloux 1991 (p.c.)
		• other	32,000			Gailloux 1991 (p.c.)
	• sub-total		176,000			Gailloux 1991 (p.c.)

APPENDIX 11: WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCE
	• wood- softwood lumber	• spruce	3,889,000			Gailloux 1991 (p.c.)
		• hemlock	238,000			Gailloux 1991 (p.c.)
		• douglas fir	291,000			Gailloux 1991 (p.c.)
		• cedar	729,000			Gailloux 1991 (p.c.)
		• jack and lodgepole pine	220,000			Gailloux 1991 (p.c.)
		• white pine	108,000			Gailloux 1991 (p.c.)
		• ponderosa, red pine	21,000			Gailloux 1991 (p.c.)
		• balsam fir	63,000			Gailloux 1991 (p.c.)
		• yellow cypress	67,000			Gailloux 1991 (p.c.)
	• sub-total		5,626,000			
	• wood industries	• fuelwood	11,100			Statistics Can. 1990f
		• chips, coniferous	1,380,100			Statistics Can. 1990f
		• chips, deciduous	66,000			Statistics Can. 1990f
		• sawdust	61,100			Statistics Can. 1990f
		• shavings	19,100			Statistics Can. 1990f
		• logs, poles	115,800			Statistics Can. 1990f
		• conif. poles	103.4			Statistics Can. 1990f
		• conif. pulpwood	26,300			Statistics Can. 1990f
	• sub-total		1,679,603			
	• non-wood products	• maple sap products	68,745	• traditional cultural benefits • recreational value of production		Statistics Can. 1990c
		• eastern cedar • cedar oil • ornamental				Mosquin 1992 (p.c.)

APPENDIX 11: WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCE
	• pharmaceuticals	• western yew tree - production of taxol (cancer fighting drug)	(still in experimental stage)	• more people receiving taxol treatment can live longer lives, have their suffering reduced • supports food chain species	greater: most taxol is exported	Gailloux 1991 (p.c.)
		• various other plants		• human productivity • longevity • improved quality of life		Whiting (in-house calculation)
	• subsistence, NWT	• fuelwood, lumber, round logs	5,000	• lower imports		Usher & Weins 1989
Other - Aquatic Plants	• ecosystem	• food	• some monetized benefits included in price of final product, most not monetized	• food/nutrition to large variety of aquatic mammals and fishes		Whiting (in-house calculation)
Other - Tundra	• cultural - psychological	• existence		• Inuit cultural identity (way of life benefits) • Non-native perceptions of northern terrain	similar	Whiting (in-house calculation)
	• optional			• tourism potential	similar	Whiting (in-house calculation)
	• ecosystem	• nutrients for wildlife	• see wildlife	• caribou, muskoxen, etc.	smaller	Whiting (in-house calculation)
Other - Desert	• ecosystem	• soil stabilization		• wind/water erosion reduction	n/a	Whiting (in-house calculation)
Other - Other forest plants	• ecosystem • primary production • oxygen production	• shelter belts • ornamentals • recreation • environmental health		• erosion control • oxygen production • carbon sink • 3-D ecosystem structures for wildlife • environmental quality and health • major food for wildlife (browse & berries), nectar for pollinators • major food source for herbivorous organisms (food chain)	similar	Mosquin 1992 (p.c.) Whiting (in-house calculation)

APPENDIX 11: WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCE
	• commercial	• blueberries, wild leeks, wild garlic, ginseng, fiddleheads		• income and employment	smaller	Whiting (in-house calculation)
	• subsistence or home consumption	• blueberries, wild leeks, wild garlic, ginseng, fiddleheads, fruits, etc.		• nutritional value • replacement value	n/a	Whiting (in-house calculation)
Other - Grasslands	• forbs, grasses & sedges	• primary production • oxygen production • recreation • ornamentals • environmental health • stock grazing		• erosion control • oxygen production • 3-D ecosystem structures • environmental quality and health • soil conditioning • food source for herbivorous organisms (leaves, nectar, pollen, wood)	smaller	Whiting (in-house calculation)
	• subsistence	• foods (eg. strawberries, mushrooms, puffballs), shelter		• home consumption • game forage	smaller	Whiting (in-house calculation)
	• cultural - psychological	• existence		• cultural identity • future potential commercial and/or recreational use	smaller	Whiting (in-house calculation)
Other - Wetlands	• subsistence	• food (eg. cranberries)		• nutritional value	smaller	Environment Canada & Wildlife Habitat Canada 1991c
	• commercial	• food (eg. cranberries)		• rural area employment and income opportunity	smaller	Environment Canada & Wildlife Habitat Canada 1991c
		• farming		• hay • water storage • water supply	smaller	Environment Canada & Wildlife Habitat Canada 1991c
	• recreational	• photography, viewing, hiking, etc.		• personal enjoyment and relaxation	smaller	Environment Canada & Wildlife Habitat Canada 1991c
	• science and information	• specimens		• knowledge and understanding	smaller	Environment Canada & Wildlife Habitat Canada 1991c

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SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCE
	• ecosystem	• habitat, breeding areas		• wildlife populations • ecosystem services	similar	Environment Canada & Wildlife Habitat Canada 1991
Other - Marine (off-shore)	• commercial algae harvest	• dulse, Irish moss, kelp	all, excluding PEI 2,074 (25,019 metric tonnes) Irish moss harvest, PEI 3,400 (14,706 metric tonnes)	• income & employment opportunities • indirect commercial benefits • medicinal/health value of products • world harvest about 2 million metric tonnes	similar	Greenshilds 1989
Other - Red and Brown Algae	• primary production • creation of 3-D ecosystem structures (kelp beds) in marine ecosystems	• major marine nurseries • essential habitat		• food stabilizers, fillers, thickeners; alginate, carrageenin • agar culture for microbiology, food preparation, stabilizers and emulsifiers, carrier substance for drugs • food chains	smaller	Greenshilds 1989
Phytoplankton	• primary production, carbohydrate production, oxygen production	• basis of ocean food chain	see fish and invertebrate benefits	• feeds invertebrates and fish • oxygen balance • food chains	smaller	Mosquin 1992 (p.c.)

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
PLANTS (CULTIVATED)	• primary production	• food • building materials • fuel (energy)		• erosion control • oxygen production • may support key food chain species	smaller	Mosquin 1992 (p.c.)
Agricultural Crops	• primary production	• food • fibre • oils		• multi-sectoral linkages generating massive income and employment throughout the economy • reduced imports • soil conditioning • erosion control • food security • nutrition	smaller	Mosquin 1992 (p.c.)
	• cultural - psychological	• way of life		• historical, social and cultural values associated with farming • maintenance of rural populations • employment opportunities for agricultural & non-agricultural workers	smaller	Whiting (in-house calculation)
	• grains	• wheat	3,025,245		larger	Agriculture Canada 1991
		• oats	85,684		larger	Agriculture Canada 1991
		• barley	grain worth 633,632 malt worth 141,100 beer worth 2,661,400		larger	Agriculture Canada 1991
		• rye	27,421		larger	Agriculture Canada 1991
	• sub-total		6,574,482			
		• wild rice		• original native peoples benefits	similar	Whiting (in-house calculation)
	• oilseeds	• flaxseed	118,004		larger	Agriculture Canada 1991
		• canola/rapeseed	769,366		larger	Agriculture Canada 1991
	• sub-total		887,370			

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
	• seeds	• mustard seed	46,402		larger	Agriculture Canada 1991; McAllister 1992 (p.c.)
		• sunflower seed	22,656		larger	Statistics Canada 1990c; McAllister 1992 (p.c.)
		• canary seed	22,101		larger	Statistics Canada 1990c; McAllister 1992 (p.c.)
	• sub-total		91,159			
	• legume/pulse	• lentils	45,214		larger	Statistics Canada 1990c; McAllister 1992 (p.c.)
		• soybeans	268,498		larger	Statistics Canada 1990c; McAllister 1992 (p.c.)
		• beans	38,230			Statistics Canada 1990c
		• peas	47,609			Statistics Canada 1990c
	• sub-total		399,551			
	• animal feed	• stored feed	1,900,000			Agriculture Canada 1990
		• grazing	1,500,000			Agriculture Canada 1990
		• tamed hay	1,800,000			Agriculture Canada 1990
		• forage seed	451,000			Agriculture Canada 1990
		• processed alfalfa	67,400			Agriculture Canada 1990
	• sub-total		5,718,400			
	• market vegetables			• domestic production and consumption • recreation and achievement value of home (non-commercial) production		Whiting (in-house calculation)
		• asparagus	7,533			Statistics Canada 1991c
		• beans	15,133			Statistics Canada 1991c
		• beets	5,701			Statistics Canada 1991c
		• cabbage	33,496			Statistics Canada 1991c
		• carrots	47,686			Statistics Canada 1991c
		• cauliflower	24,373			Statistics Canada 1991c
		• celery	8,230			Statistics Canada 1991c

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SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
		• sweet corn	71,378			Statistics Canada 1991c
		• field cucumbers	19,671			Statistics Canada 1991c
		• greenhouse cucumbers	29,073			Statistics Canada 1991c
		• lettuce	24,775			Statistics Canada 1991c
		• onions	25,041			Statistics Canada 1991c
		• parsnips	1,592			Statistics Canada 1991c
		• peas	30,432			Statistics Canada 1991c
		• peppers	17,813			Statistics Canada 1991c
		• radishes	3,412			Statistics Canada 1991c
		• rutabagas	18,016			Statistics Canada 1991c
		• spinach	2,011			Statistics Canada 1991c
		• field tomatoes	98,259			Statistics Canada 1991c
		• greenhouse tomatoes	33,479			Statistics Canada 1991c
		• cantaloupe	983			Agriculture Canada 1990
	• sub-total		518,087			
	• food berries			• recreational value of growing and harvesting • subsistence		Whiting (in-house calculation)
		• blueberries	35,548			Agriculture Canada 1991
		• cranberries	21,403			Agriculture Canada 1991
		• raspberries	14,543			Agriculture Canada 1991
		• strawberries	47,024			Agriculture Canada 1991
	• eating and wine	• grapes	34,411			Statistics Canada 1991c
	• sub-total		152,929			
	• tree fruits			• landscape beauty • wildlife food		Whiting (in-house calculation)
		• apples	109,890 cider value 64,100			Statistics Canada 1991c W3
		• peaches	35,189			Statistics Canada 1991c

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SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
		• pears	7,870			Statistics Canada 1991c
		• sweet cherries	5,802			Statistics Canada 1991c
		• sour cherries	3,499			Statistics Canada 1991c
		• plums, prunes	2,048			Statistics Canada 1991c
		• apricots	1,294			Agriculture Canada 1990
	• sub-total		165,592			
	• subsistence	• collecting, gathering • NWT	5,000	• Inuit traditional way of life		Usher & Weins 1989
	• brewing	• hops	11,300			Statistics Canada 1990a
	• horticultural	• ornamental plants	455,300	• landscape features • aesthetic appeal	smaller	Statistics Canada 1990e
	• nursery	• general nursery	229,000		smaller	Statistics Canada 1990c
		• sod	91,000		smaller	Statistics Canada 1990c
	• sport-related (golf, x-country running, hiking, canoeing, skiing, etc.)		see Wildlife, Recreation and Parks benefits	• landscape beauty • aesthetic appeal • quality of experience	smaller	Whiting (in-house calculation)
Plant-sourced pesticides	• genus chrysanthemum	• pyrethrins (pesticide)		• high degree of specificity		Pimentel 1991
Other	• smoke	• tobacco	261,669	• disbenefits of health related problems • fires (house, forest)	larger	Statistics Canada 1991c; McAllister 1992 (p.c.); Whiting (in-house calculation)
	• plant-sourced products	• honey	49,628	• pollination, propagation • recreational pursuit	smaller	Agriculture Canada 1990 Whiting (in-house calculation)
Forest trees	• Forest Plantations	• wood\fibre industrial products	approx. 3% of natural forest production value 225,000	• 4 - 5 times greater productivity per acre	smaller	Wilson 1991 (p.c.)
		• Christmas trees		• natural Christmas trees • fund raiser for service clubs	similar	Whiting (in-house calculation)

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SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
ANIMALS (WILD)	• herbivory and/or carnivory	• food • recreation • subsistence • fishing • filming • research		• maintain planetary health • prime food chain links • major role in symbiosis • animal and plant population moderation • soil conditioning and sediment bioturbation • decomposition • communications (songs, calls) • animal beauty and feelings	major positive effect on other countries (migrations, exports, etc.)	Agriculture Canada 1991 Mosquin (p.c.) Chapter 4 Table 2
Mammals	• commercial - trapping			• population management • income to rural areas • indicator of environmental health		Whiting (in-house calculation)
		• badger	6,739			Statistics Canada 1990d
		• black bear	182.1			Statistics Canada 1990d
		• polar bear	603.4			Statistics Canada 1990d
		• beaver	4,473.5			Statistics Canada 1990d
		• coyote	355.8			Statistics Canada 1990d
		• ermine	50.5			Statistics Canada 1990d
		• fisher	403.7			Statistics Canada 1990d
		• fox - blue	2.4			Statistics Canada 1990d
		• fox - red	462.4			Statistics Canada 1990d
		• fox - silver	8.2			Statistics Canada 1990d
		• fox - white	24.0			Statistics Canada 1990d
		• lynx	1,149.6			Statistics Canada 1990d
		• marten	11,254.1			Statistics Canada 1990d
		• mink	1,982.4			Statistics Canada 1990d
		• muskrat	455.9			Statistics Canada 1990d
		• otter	314.8			Statistics Canada 1990d

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SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
		• raccoon	93.7			Statistics Canada 1990d
		• skunk	.2			Statistics Canada 1990d
		• squirrel	66.3			Statistics Canada 1990d
		• wildcat	44.5			Statistics Canada 1990d
		• wolf	319.8			Statistics Canada 1990d
		• wolverine	88.1			Statistics Canada 1990d
	• sub-total		29,075			
	• research animals	• ferret • mink • marine mammals • primates • other wild species		48 animals 166 animals 41 animals 2138 animals 5786 animals		McWilliam 1992 (p.c.)
	• cultural - psychological	• way of life		• heritage values for native peoples • by-products used in art (sculptures, etc.)	smaller	Whiting (in-house calculation)
Wildlife	• recreation - Newfoundland and Labrador	• hunting	expenditures 41,900 net economic value 20,800		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 39,000 net economic value 7,500		smaller	Filion *et al.* 1988
	• recreation - Prince Edward Island	• hunting	expenditures 4,200 net economic value 2,900		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 15,300 net economic value 1,900		smaller	Filion *et al.* 1988
	• recreation - Nova Scotia	• hunting	expenditures 49,700 net economic value 28,400		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 105,700 net economic value 19,800		smaller	Filion *et al.* 1988

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	• recreation - New Brunswick	• hunting	expenditures 56,600 net economic value 26,400		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 80,100 net economic value 14,000		smaller	Filion *et al.* 1988
	• recreation - Quebec	• hunting	expenditures 225,200 net economic value 71,500		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 743,600 net economic value 98,400		smaller	Filion *et al.* 1988
	• recreation - Ontario	• hunting	expenditures 314,000 net economic value 164,500		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 1,304,800 net economic value 206,600		smaller	Filion *et al.* 1988
	• recreation - Manitoba	• hunting	expenditures 64,700 net economic value 19,000		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 130,600 net economic value 20,800		smaller	Filion *et al.* 1988
	• recreation - Saskatchewan	• hunting	expenditures 42,300 net economic value 17,900		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 181,500 net economic value 16,300		smaller	Filion *et al.* 1988
	• recreation - Alberta	• hunting	expenditures 124,700 net economic value 53,000		smaller	Filion *et al.* 1988

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		• non-consumptive and other activities	expenditures 537,100 net economic value 64,500		smaller	Filion *et al.* 1988
	• recreation - British Columbia	• hunting	expenditures 137,400 net economic value 47,300		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 901,300 net economic value 85,700		smaller	Filion *et al.* 1988
	• recreation - Northwest Territories	• hunting	value of hunting by non-residents of NWT 8,500		smaller	Lloyd 1992 (p.c.)
	• recreation - Canada	• hunting	expenditures 1,060,300 net economic value 451,700		smaller	Filion *et al.* 1988
		• non-consumptive and other activities	expenditures 4,038,900 net economic value 535,600		smaller	Filion *et al.* 1988
	• cultural - psychological: Canada	• existence	estimates range from 144,400 to 1,001,300	• three studies used to extrapolate to national figures		Filion & Jacquemot 1992 (p.c.)
	• cultural - psychological: British Columbia	• preservation value	131,751		smaller	Eastman 1992 (p.c.)
	• cultural - psychological: British Columbia	• existence	.160 per household over 5 years to stop all oil spills in west coast area	• excludes benefits identified in the United States	larger	Rowe *et al.* 1991

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	• cultural - psychological	• existence		• cultural identity for native peoples • religious value for native and other peoples • way of life benefits • strength to communities	smaller	Lloyd 1992 (p.c.)
		• optional use: non-consumptive uses		• 15.3 million Canadians indicated interest in participating (14% more than actually did) in 1981	large	Filion *et al.* 1988
		• optional use: involvement in wildlife organizations		• 8.0 million Canadians indicated an interest in participating (618% more than actually did) in 1981	smaller	Filion *et al.* 1988
		• optional use: hunting		• 3.5 million Canadians indicated an interest in participating (96% more than actually did) in 1981	larger	Filion *et al.* 1988
	• subsistence - Northwest Territories	• hunting, trapping	50,000 - 75,000	• estimated 5 million Kg. of meat and fish • estimated 80% of native households has at least one person who harvests	smaller	Usher & Weins 1989 Lloyd 1992 (p.c.)
Birds, Murres	• subsistence	• food and recreation	3,750 (@ $5 each)	• estimated 750,000 Murres harvested in Newfoundland • provision of food for an estimated 15,000 households	nil	W57 (Equinox article) Whiting (in-house calculation)
Ducks/Geese	• subsistence	• food		• approximately 500,000 ducks hunted by natives • approximately 350,000 geese hunted by natives • approximately 50,000 aboriginal hunters in all of Northern Canada	nil	Thompson 1991

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Fish				• inter-sectoral linkages creating income and employment • subsistence • fish exports • home consumption • way of life • cultural & social benefits	larger	Whiting (in-house calculation)
bony fish, saltwater	• benthic	• cod	224,216	• oil for vitamins		Fisheries & Oceans 1991
		• haddock	25,350			Fisheries & Oceans 1991
		• redfish	36,972			Fisheries & Oceans 1991
		• halibut	28,841			Fisheries & Oceans 1991
		• flatfishes	43,872			Fisheries & Oceans 1991
		• turbot	12,397			Fisheries & Oceans 1991
		• pollock	19,862			Fisheries & Oceans 1991
		• hake	16,509			Fisheries & Oceans 1991
		• cusk	1,837			Fisheries & Oceans 1991
		• catfish	520			Fisheries & Oceans 1991
		• other	19,580			Fisheries & Oceans 1991
	• sub-total		429,956			
	• pelagic and other finfish	• herring	107,933			Fisheries & Oceans 1991
		• mackerel	5,447			Fisheries & Oceans 1991
		• tuna	8,801			Fisheries & Oceans 1991
		• alewife	4,185			Fisheries & Oceans 1991
		• eel	2,882			Fisheries & Oceans 1991
		• salmon, Pacific	224,147			Fisheries & Oceans 1991
	• native commercial	• salmon, Pacific	(24,200)			Hinch 1992 (p.c.)
		• skate	52			Fisheries & Oceans 1991
		• smelt	1,381			Fisheries & Oceans 1991
		• capelin	19,019			Fisheries & Oceans 1991
		• other	9,789			Fisheries & Oceans 1991
	• sub-total		383,636			

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	• crustaceans and molluscs	• food		• major food chains in oceans and land		McAllister 1992 (p.c.)
		• clams	32,727			Fisheries & Oceans 1991
		• oysters	8,855			Fisheries & Oceans 1991
		• scallops	93,239			Fisheries & Oceans 1991
		• squid	787			Fisheries & Oceans 1991
		• lobster	263,680	• important tourism generator		Fisheries & Oceans 1991 Whiting (in-house calculation)
		• shrimp	84,848			Fisheries & Oceans 1991
		• crab	52,851			Fisheries & Oceans 1991
		• other	5,459			Fisheries & Oceans 1991
		• geoduck	12,000			Government of Canada 1991d
	• sub-total		554,446			
	• bony fish, inland waters	• trout, pike, whitefish, smelt, perch, etc.	78,000			Fisheries and Oceans, 1991
	• native commercial - east and north		(35,000)			Hinch 1992 (p.c.)
	• research	• research, teaching, testing		• 280,318 fish		McWilliam 1992 (p.c.)
	• Recreational - Canada	• sport fishing	• resident fishermen expenditures: 2,228,200 • fishing investment by resident fishermen: 1,819,300 • food value of fish eaten by residents (replacement value of $1/pound): 92,145.6	• consumer surplus • health effects • relaxation	approx 25% of Canadian benefits	Fisheries & Oceans 1991 Whiting (in-house calculation)

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	• Recreational - Saskatchewan	• sport fishing	• angler expend. 75,679 • consumer surplus 34,200		smaller	Crouter 1991 (p.c.)
	• subsistence	• native fishery	• atlantic 100 • pacific 19,400		smaller	Hinch 1992 (p.c.)
Sponges	• provide critical 3-D ecosystem structure on oceanic floor			• decomposers (primary and secondary detritivory) • water filtration (filter feeders)		Statistics Canada 1990f; Statistics Canada 1990e
Coelenterates	• ecosystem (see Table 2)					Mosquin 1992 (p.c.)
Combjellies	• ecosystem					Mosquin 1992 (p.c.)
Flat worms	• ecosystem					Mosquin 1992 (p.c.)
•ibbon worms	• ecosystem					Mosquin 1992 (p.c.)
Gastrotrichs	• ecosystem					Mosquin 1992 (p.c.)
Rotifers	• major base of freshwater food chains	• none		• filter feeders on phytoplankton & microinvertebrates • some decomposers	none known	Statistics Canada 1990f; Statistics Canada 1990e
Kinorhynchs	• ecosystem					Mosquin 1992 (p.c.)
Nematodes	• ecosystem					Mosquin 1992 (p.c.)
Annelids	• vermicomposting			• fish bait		Mosquin 1992 (p.c.)
Arachnids	• major food source for insects, birds			• control insect populations		Mosquin 1992 (p.c.)
Water Bears		• unknown		• herbivores & carnivores on plant and animal juices; possibly are food sources for other microinvertebrates		Mosquin 1992 (p.c.) Whiting (in-house calculation)
Insects	• food for insects, birds, amphibians, mammals	• food chain		• control harmful insects, recycle plants • symbiotic relationship with plants		Mosquin 1992 (p.c.)
	• pollination	• pollinators of trees, crops, other plants	value attributable 1,000,000 rental income to hive owners of approx. 1,800		smaller	Globe & Mail 1992; Agriculture Canada 1990; Charbonneau 1992 (p.c.); Whiting (in-house calculation)

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	• pheromones	• insect control		• non-persistent, highly specific pest control		
Starfish & Kin						Mosquin 1992 (p.c.)
Hemichordates						Mosquin 1992 (p.c.)
Tunicates						Mosquin 1992 (p.c.)
Lamprey & Kin	• carnivory			• disbenefits of parasitism on fish of commercial value		Mosquin 1992 (p.c.)
Sharks & Kin	• carnivory					Mosquin 1992 (p.c.)
Amphibians	• herbivory (frog tadpoles) and carnivory	• meat, pet trade, zoo trade, research, university teaching		research use: • 14,425 frogs • 3,692 salamanders • 3,964 other amphibians adults: • food for animal groups • tadpoles: major food source for fish, birds • communication value (frog chorus in spring)	smaller	Statistics Canada 1991c; McWilliam 1992 (p.c.)
Reptiles	• carnivory • herbivory	• turtles • snakes		• many breeding companies are American • 5,232 specimens • 254 specimens • research use		McWilliam 1992 (p.c.)
	• ecosystem					Mosquin 1992 (p.c.)
	• commercial	• footwear, purses, watchbands		• income • employment		Whiting (in-house calculation)

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
ANIMALS, DOMESTIC						
Fish	• aquaculture	• more than half salmon, trout, oysters, mussels harvested	48,300	• inter-sectoral linkages creating income and employment • conservation of wild species • technology development	similar	Government of Canada 1991c
Birds	• poultry	• chicken	973,383		smaller	Statistics Canada 1990c
		• turkey	230,638		smaller	Statistics Canada 1990c
		• eggs	518,707		smaller	Statistics Canada 1990c
		• ducks, geese, other	186,895		smaller	Statistics Canada 1990c
	• birds for research purposes	• chickens • ducks • pigeons • turkeys • Japanese quail • others		• 221,677 • 4,256 • 1,503 • 16,106 • 16,266 • 10,192	smaller	McWilliam 1992 (p.c.)
Mammals	• industry	• raw hides, leather	246,100	• human clothing, footwear		Statistics Canada 1989
	• agricultural	• bovine, meat	4,116,295	• ethnic foods • nutrition • inter-sectoral linkages • income and employment • food security		Statistics Canada 1990c Whiting (in-house calculation)
		• bull semen, exports	23,500	• proliferation of Canadian genetic material	larger	Agriculture Canada 1990
		• purebred cattle exports, other	14,900	• improved productivity • national reputation	larger	Agriculture Canada 1990
		• bovine, milk products, farm gate value	3,135,607	• nutrition • health related benefits	smaller	Statistics Canada 1990c
		• sheep, mutton	4,004		smaller	Statistics Canada 1990c
		• sheep, lamb	29,947		smaller	Statistics Canada 1990c
		• sheep, wool	1,776		smaller	Statistics Canada 1990c
		• hog, red meat	1,800,000		smaller	Agriculture Canada 1990

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	• cultural - psychological	• way of life		• historical, social and cultural values associated with farming • maintenance of rural populations • employment opportunities for agricultural and non-agricultural workers		Whiting (in-house calculation)
	• game ranching - incomplete	• elk	5.0 female 3.0 male	• better adaptation to environment		Jurke 1991 (p.c.)
		• red deer	approx 2.5 per animal (breeding)	• more suited to grazing existing vegetation than bovine species		Fundy Deer Farmers Ltd. 1991 (p.c.)
	• fur farming	• fox	4,224			Statistics Canada 1990d
		• mink	25,771			Statistics Canada 1990d
	• pets	• dogs	approx. 127,100 ($50 apiece)	• approx 2.542 million in Cdn households • companionship • 634 dog clubs associated with the Canadian Kennel Club • therapeutic benefits	smaller	Statistics Canada Household Surveys Division 1989; Pimentel 1991; Whiting (in-house calculation)
		• cats	approx. 13,020 ($5 apiece)	• approx 2.604 million in Cdn households • therapeutic benefits • companionship	smaller	Statistics Canada Household Surveys Division 1989; Pimentel 1991

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	animals for research	• 41 marine mammals • 10306 dogs • 4718 cats • 20,473 cattle • 243 goats • 656 horses • 17,313 sheep • 17,649 swine • 3,059 gerbils • 38,473 guinea pigs • 6,078 hamsters • 818,555 mice • 180 mini pigs • 29,544 rabbits • 395,987 rats		• development of new human and veterinarian pharmaceuticals • testing of health safety of pharmaceuticals and cosmetics • prolong life, health and quality of life of humans, domestic, zoo and some wild animals	smaller	McWilliam 1992

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MICRO-ORGANISMS (WILD)	(see Table 2 and Chapter 4)					
Viruses	• regulate abundance of animal and plant life	• research		• interspecific transfer of genes • super-abundant in warm fresh and marine waters - ecosystem function mainly not known • Moderate bacterial populations with bacteriophages	smaller	Statistics Canada 1989; Fisheries & Oceans 1990; Agriculture Canada 1990; Statistics Canada 1990d; *Government* of Canada 1991e
Bacteria	• convert organic molecules into methane • hydrolize large molecules • symbionts with many higher animals & plants	• make yogurt • *Bacillus thuringiensis* (spray for spruce budworm and gypsy moth) • research into new antibiotics • research on ecosystem processes and interrelationships		• in animal intestines - essential for digestion (make methane) • control animal populations • reduce sulphur in water & sediments - essential for protein production • carry out photosynthesis (both aerobically and anaerobically) • fix nitrogen from air and in plant tissues • produce biomass from purely inorganic compounds • oxidize nitrogen, methane, sulphur • ferment almost any organic molecules • (In other words, bacteria are more important to maintaining ecosystem processes than any other group of organisms.)	smaller	Mosquin 1992 (p.c.); McAllister 1992 (p.c.)
Cyano-bacteria	• primary production • starting point for major food chains • oxygen production • symbionts in most lichens, many ferns and mosses	• as essential lichen partners, they provide nitrogen to boreal forest and tundra ecosystems • phytoplankton		• as essential lichen partners, they provide nitrogen to boreal forest and tundra ecosystems	smaller or none	Mosquin 1992 (p.c.)

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Unicellular Algae	• primary production • starting point for major food chains	• plankton		• carbon dioxide fixation • some decomposition (species with "gullets") • symbionts in most lichens, coelenterates • soil conditioners	smaller	Mosquin 1992 (p.c.)
Fungi	• primary decomposition • nutrient transport in forest soils (enable plant nutrition) • mycorrhizal association with trees, shrubs, herbs • natural control of insect pest populations	• wild mushroom harvesting/eating • fermentation of wines • fermentation of beers	• wild mushroom harvests estimated $12 to $30 million annually	• soil conditioners • as listed in column 2 • enhanced growth of timber and crops • reduction in fertilizer needs (nitrogen and phosphorus)	smaller	Government of Canada 1991d; McAllister 1992 (p.c.)
MICRO-ORGANISMS (CULTURED)						
Protozoa	• microsporidia • apicomplexa families	• insect pathogens		• control insect populations • highly specific		Pimentel 1992
Nematodes	• entomopathogenic nematodes	• kill soil-inhabiting insect pests		• more environmentally safe than traditional pesticides		Pimentel 1992
Bacteria	• decomposition	• composting material for gardens • septic tank inoculation	• value of sales of commercial compost and equipment attributable to bacteria doing the decay	• soil formation • decrease in anthropogenic waste	smaller	Mosquin 1992 (p.c.)
Bacteria	• for vaccines, medication	• penicillin, sulfa		• check the spread of infections and disease	smaller	Whiting (in-house calculation)
Bacteria	• for dairy products	• cheese, yogurt, acidophilus so lactose-intolerant people may consume milk products		• increased storage capability of food (e.g. cheese) • variety in diet	smaller	Whiting (in-house calculation)

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Bacteria	for agriculture *Baccillus thuringiensis* *B. thunin* *Agrobacterium radiobacter*	• kill forest pests (gypsy moth, spruce budworm), pests of agricultural crops, stored grains, and ornamentals • inoculant for the control of crown gall		• 1 unit = 16 billion I.U. 1983 142,100 units shipped 1984 641,000 units shipped 1985 1,604,600 units shipped	smaller	Pimentel 1991; Cook 1992 (p.c.) Dept. of Tourism and Parks, P.E.I. 1991
Fungi	commercial mushrooms	• food	153,348			Statistics Canada 1991c
	yeasts	• beer and wine brewing, alcohol formation	(beer value 2,661,400) (wine value 257,100) yeast value 700	• lifestyle • social benefits	smaller	Statistics Canada 1990a
	mushroom	• fertilizer		• high in organic matter and nutrients	n/a	Whiting (in-house calculation)
	Metarhizium anisopliae	• cockroach killer	• soon to be marketed by EcoScience	• victim will carry spores and spread them through colony, killing others • highly specific		National Geographic 1992
	Aschersonia aleyrodis *Beauveria bassiana*	• microbial pesticide used on plant-sucking insects			smaller	Pimentel 1991

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Virus	nuclear polyhedrosis virus (NPV) for example: *Choristoneura fumiferana*, *Gilpina hercyniae*, *Lymantria dispar*, *Malacosoma disstria*, *Neodiprion leconti*, *N. sertifer*, *N. swainei*, *Orgyia pseudotsugata* in use: NPV of douglas fir tussock moth, NPV of red-headed pine sawfly	• insect pest management • used in growth of trees through inoculative augmentation, and as an aid in introduction and establishment		• 160 Ha sprayed with Virtuss and 40 Ha sprayed with TM Biocontrol-1 against the Tussock Moth • 140 Ha sprayed with Gypchek and 80 Ha (the Royal Botanical Gardens) Sprayed with Disbarvirus; both experimental against the Gypsy Moth • 722 Ha sprayed against the Red-Headed Pine Sawfly • natural capability to cause disease at epizootic levels • simple viral genome can be manipulated by recombinant DNA techniques • very versatile and compatible with other pest control methods • disbenefit is indirect reduction of entomophagous or entomogenous organisms through eradication of the host insect	smaller	Pimentel 1991; Cunningham 1992 (p.c.)

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ECOSYSTEMS	(see Table 2)					
National Parks	• preserve representative examples of ecosystem integrity for Canada as a whole	• protecting the ecology of the planet • educating the public about fundamental values of the planet • recreation	• revenue 37,771 • attributable expenditures of visitors estimated at 600,000 • 145,000 in taxes, duties, royalties	• serve as a symbolic hope that it may be possible to prevent the near-total degradation of ecological processes and functions of the Earth's ecosphere • induce investments for local people and tourist services • provide employment and income opportunities for mostly rural area residents • create services which might not otherwise be viable to the benefit of local area residents	smaller	Perron 1991 (p.c.); Whiting (in-house calculation)
Provincial Parks	• preserve representative natural and cultural resources of each province	• protecting significant natural resources • creating natural areas for recreation • education, interpretation of natural resources			smaller	Whiting (in-house calculation)
	• Newfoundland		• average party expenditure of .545 in 1990 • total direct revenue 642	• 951,000 visitors to Natural Environment Parks • 109,232 hectares in Wilderness and Ecological Reserves	smaller	Dept. of Environment & Lands 1990; Vaughan 1991; Depart. of Environment & Lands 1991
	• Prince Edward Island	• creating natural areas for recreation • management of natural areas	• 1,104 in revenue from golf, skiing, camping & concessions	• 69,135 people camping • 313,836 day visits (excl. campers)	smaller (78.6% Canadian)	Murray 1992 (p.c.)
	• Nova Scotia					

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	New Brunswick	• recreation, interpretation	• revenue: 1,700 • N.B. resident expenditures: 205,900 • non-resident • expenditures: 87,100	• higher quality of life	smaller	Tait 1991 (p.c.)
	Quebec (incomplete)	• recreation, interpretation	• visitor expenditures: 20,000	• 66,500 visitors	smaller	Lemieux 1992 (p.c.)
	Ontario	• natural environment	• revenue 6,444.5	• 3,496,699 visitors	smaller approx 10% of visitors	Ontario Ministry of Natural Resources 1991; Marriage 1992 (p.c.)
		• nature reserve		• 34,332 visitors	smaller	Ontario Ministry of Natural Resources 1991; Marriage 1992 (p.c.)
		• wilderness	• revenue 501.4	• 201,241 visitors	smaller	Ontario Ministry of Natural Resources 1991; Marriage 1992 (p.c.)
	Manitoba					
	Saskatchewan		• revenue 5,887 • park-related expenditures 82,127 • estimated consumer surplus 25,000	• 2,467,496 visitors	smaller approx 3.5% of visitors	Crouter 1991 (p.c.)
	Alberta					
	British Columbia	• aesthetic pleasure, cultural, social system base, identity	• revenue 3,790	• 379 parks total area of 5,340,000 ha • 117 ecological reserves total area of 155,200 ha • 19,642,000 park visitors	smaller	Eastman 1992 (p.c.)
Territorial Parks	Yukon	• Herschel Island Nature Preserve	• tourism benefits directly attributable: 75.0	• 300 visitors	smaller	Fuller 1992 (p.c.)
		• Coal River Springs Ecological Preserve	• estimated visitor spending: 4.0	• estimated 12 visitors	n/a	Fuller 1992 (p.c.)
	Northwest Territories	• park fee revenue	• approx. 100	• 12,000 - 15,000 visitors annually	smaller	Lloyd 1992 (p.c.)

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Provincial Forests	• British Columbia	• aesthetic pleasure, cultural, social system base, identity		• 1,410,000 visitors	smaller	Eastman 1992 (p.c.)
Wetlands	• all	• all	estimated 10,000,000		larger	Patterson 1991
Eco-tourism	• Canadian Regions	• adventure travel, • viewing & experiencing nature	gross revenue per region: Ontario/Quebec - 107,500 Maritimes - 5,200 Newfoundland/ NWT - 45,700	• 206 operators (Ontario/Quebec) • 89 operators (Maritimes) • 112 operators (Nfld, NWT) • 29 package tours for Baffin Island, 10 for Keewatin • new employment & income opportunities for isolated area residents & others	smaller	Ethos Consulting Ltd. 1990; Eastman 1992 (p.c.)
	• Prince Edward Island	• Atlantic Marine Wildlife Tours • seal watching • bicycle touring	5 days - 1.4 1 day - 0.8 ($60-120/day)		smaller	Ethos Consulting Ltd. 1990
	• Newfoundland & Labrador	• Adventure travel	3,000 outfitting industry	• 1.6 million person-visits	smaller 40,200 visitors from USA	Ethos Consulting Ltd. 1990
	• Saskatchewan	• primarily non - consumptive wildlife activities	expenditures: 105,970 consumer surplus: 29,700			Crouter 1991 (p.c.)
	• British Columbia	• guest ranch • fishing lodge or resort • guide outfitting industry • marine tourism • adventure travel	3,500 89,000 22,100 222,000 55,700		smaller	Eastman 1992 (p.c.)

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	• Yukon	• wilderness & adventure travel		• Herschel Island visitors: - arctic/wilderness experience (33%) - arctic flowers, vegetat., landscapes (23%) - view wildlife (19%) - cultural heritage (10%) • number of wilderness & adventure tour co.'s: 75		Fuller 1992 (p.c.)
	• Northwest Territories	• viewing caribou • viewing polar bears	tourism income 50 tourism income 200	• income opportunities for native peoples • natural setting interpretation values		Lloyd 1992 (p.c.)
Institutions: Museums						
	• Provincial Museum of Alberta	• research • education • preservation	gift shop revenue 873	• 441,898 visitors • understanding of history and impacts of a decrease in grassland biodiversity	smaller (21.2% foreign)	McGillivray 1992 (p.c.)
	• Sandilands Forest Centre Museum	• viewing • touching		• increased forestry and environmental awareness for visitors • 5,000 students; 3,000 other visitors	smaller (1%)	Beaven 1991 (p.c.)
	• Whiteshell Natural History Museum	• viewing	revenue 45.0	• education of 15,000 visitors about the park's resources	smaller (6%)	Clarke 1991 (p.c.)
	• Nova Scotia Museum Complex	• exhibition, interpretation, education, research	n/a		n/a	Cloutier 1991 (p.c.)

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	• Canadian Museum of Nature	• education, research, preservation, provide knowledge for conservation, management and exploitation of natural resources and for biotechnology	revenue 264.0	• 512,000 exhibit visitors • 69,000 enquiries answered • 160,785 travelling exhibit visitors • 90,000 student tours • 40,000 new specimen acquisitions • best-selling books, eg. Birds of Canada with over 200,000 sold. Helps attract tourists	smaller	Government of Canada 1990b; McAllister 1992 (p.c.)
	• Manitoba Museum of Man and Nature	• education, research, interpretation, preservation	revenue 870	• preserve the heritage of Manitoba, research in a wide range of natural history fields; bats, toads, post-fire succession etc..	smaller	DeCosimo 1991 (p.c.)
	• Redpath Museum, McGill University			• 8,000 visitors • travelling exhibit on the St. Lawrence River valley	smaller (25%)	Pasztor 1991 (p.c.)
	• Royal Ontario Museum	• collect and form record of natural specimens, research, educational experiences		• 952,222 visitors in 1990 • research re. bluebirds, an endangered species, *crataequs* & *Acer* systematics, quarternary climatic & vegetation change • maintenance of collections as indicators of habitat destruction and environmental change • general knowledge about the diversity of life • species lists may be used to establish reserved areas of high species diversity • information for interpretation programs in parks • vascular plant herbarium with 250,000 specimens	smaller	Robertson 1991 (p.c.); De Carlo 1992 (p.c.)

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	• B.J. Hales Museum (Brandon University)	• education, training, general awareness		• 3,400 visitors • show the value of conserving resources by showing and providing information on species that are endangered	smaller (0.3%)	Letkeman 1991 (p.c.)
	• Langley Centennial Museum and National Exhibition Centre	• education, workshops, exhibitions	revenue 6.499	• 24,997 visitors	n/a	Thorpe 1992 (p.c.)
	• Cowichan and Chemainus Valleys Ecomuseum Society	• heritage education, eco-tours, regional tourism development	revenue 391.	• 378,781 visitors • preserve and present history and the living heritage of the British Columbia forest in the valleys • increase resident and visitor awareness • developing cultural tourism as a sustainable resource	smaller	Wood 1992 (p.c.)
Nature Centres	• Shuswap Lake Provincial Park Nature House	• educate visitors about area's natural history		• improved knowledge		Enns 1991 (p.c.)
	• Kortright Centre for Conservation	• education, displays, nature presentation	revenue 425.0	• public education for 110,000 visitors • protect existing wildlife habitat • introduce visitors to the challenges society faces in balancing its needs with ecological systems	smaller (2%)	Burchette 1991 (p.c.)
	• Shubenacadie Wildlife Park	• rearing, breeding, education		• increased populations of wild birds (rearing/release) • increased populations of endangered species (breeding programs) • education/experience • breeding stock of endangered species • education/information for 330,000 visitors	smaller (5%)	Vissers 1991 (p.c.)

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	• Salmonier Nature Park	• education, research, rehabilitation	gate revenue 8.6	• 30,000 visitors • 1,200 hectares reserved	smaller (18%)	Jarvis 1991 (p.c.)
	• Waskasoo Park Nature Centre	• education, interpretation		• 58,000 visitors	smaller (1%)	Robertson 1991 (p.c.)
	• Saskatchewan Fish Culture Station	• information, restocking		• 15,000 visitors	smaller (10%)	Fisher 1991 (p.c.)
Herbaria	• University of British Columbia Herbarium	• research		• housing of 500,000 plant specimens	smaller (25%)	Straley 1991 (p.c.)
	• University of Guelph Arboretum	• conservation	75.0	• survival of all species • visitor recreation and appreciation	smaller (7%)	Ronald 1991 (p.c.)
	• Butchart Gardens	• viewing, appreciation, enjoyment		• 750,000 visitors		Clarke 1991 (p.c.)
	• Memorial University Botanical Gardens	• general public and student interest, research and enjoyment	2.0	• community secondary benefits from garden's purchases • 30,000 visitors		Jackson 1991 (p.c.)
	• Allan Gardens Conservatory	• exhibits exotic plant sp. and seasonal flowering crops		• approx. 100,000 visitors annually	n/a	Powers 1992 (p.c.)
Zoological Institutions	• Valley Zoo, Edmonton	• viewing, sales revenues	revenue 757.2	• public display • education • recreation	smaller (6%)	Leeb 1991 (p.c.)
	• Assiniboine Park Zoo	• viewing, sales, breeding stock	revenue 781.1	• increase in many CITES listed species • public education/information • 814,000 attendance		Roots 1991 (p.c.)
	• Société Zoologique de Granby Inc.	• education, preservation, recreation	income 3,214.7 profit 499.0	• 502,000 visitors • staff of 263		Société Zoologique de Granby 1990
	• Calgary Zoo, Botanical Garden and Prehistoric Park	• education, research, recreation		• 775,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991

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	• West Edmonton Mall Game Farm	• education, recreation		• 13 staff plus 7 volunteers		Canadian Association of Zoological Parks and Aquariums 1991
	• Alberta Wildlife Park			• 147,000 attendance • 20 employees		Canadian Association of Zoological Parks and Aquariums 1991
	• Vancouver Game Farm	• education, recreation				Canadian Association of Zoological Parks and Aquariums 1991
	• Kamloops Wildlife Park	• education, recreation		• 55,000+ attendance		Canadian Association of Zoological Parks and Aquariums 1991
	• Okanagan Game Farm Ltd.	• education, profit		• 100,000 attendance		Canadian Association of Zoological Parks and Aquariums 1991
	• Stanley Park Zoological Gardens	• education, recreation		• 1,200,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Crystal Garden, Victoria	• education, recreation		• 200,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Wild Kingdom Zoo, Dauphin	• education, recreation, profit				Canadian Association of Zoological Parks and Aquariums 1991
	• Grouse Lake Park Zoo, Manitoba					Canadian Association of Zoological Parks and Aquariums 1991
	• Thompson Zoo	• education		• 45,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Magnetic Hill Zoo, N.B.	• education, outreach, tourism		• 100,000+ visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Cherry Brook Zoo, St. John	• education, recreation, awareness, non-profit		• approx 65,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991

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	• Oaklawn Farm, N.S.	• education, profit		• 70,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Upper Clements Wildlife Park	• recreation, education, tourism		• approx 90,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Bowmanville Zoological Park	• education, recreation, tourism		• 170,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Killman Zoo, Ont	• education		• 30,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• African Lion Safari and Game Farm, Ont	• education, recreation, tourism		• 400,000+ visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• The Tortoise Farm, Ont	• education, recreation				Canadian Association of Zoological Parks and Aquariums 1991
	• Northern Frontier Zoo, Ont	• education		• 25,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Storybook Gardens, Ont	• education		• 265,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Pheylonian Animal Haven, Ont	• education, animal shelter		• 19,000 visitors • self-funded		Canadian Association of Zoological Parks and Aquariums 1991
	• Jungle Cat World Inc., Ont	• education, viewing, touching		• 107,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Ken Jen Petting Zoo, Ont	• touching, education		• 250,000+ visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Riverview Park and Zoo, Ont	• education, viewing, recreation		• approx 300,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991

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	• Reptile Breeding Foundation, Ont	• education, breeding		• 12,127 visitors • reptile breeding foundation		Canadian Association of Zoological Parks and Aquariums 1991
	• Greenview Aviaries-Game Farm, Ont	• education		• 22,000 attendance		Canadian Association of Zoological Parks and Aquariums 1991
	• Colasanti Tropical Gardens, Ont	• education, interpretation		• 500,000 attendance		Canadian Association of Zoological Parks and Aquariums 1991
	• Chippewa Wildlife Exhibit, Ont	• education		• approx 25,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Metropolitan Toronto Zoo	• education, recreation, viewing		• approx 1,250,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Ocean Park Ltd., P.E.I.	• tourism, recreation		• 22,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Jardin Zoologique de Bonaventure, P.Q.	• education		• 25,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Jardin Zoologique du Québec	• education, interpretation, recreation		• 225,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Parc Safari Africain (Quebec) Ltd.	• education, recreation, tourism		• 300,000+ visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Centre Naturanimo Vallée de la Matapedia Inc.	• education, recreation	• revenue 79.2			Canadian Association of Zoological Parks and Aquariums 1991
	• Zoo Sauvage de St. Felicien	• education, interpretation, recreation		• approx 250,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
	• Forestry Farm Zoo, Sask.	• education, interpretation, recreation		• 100,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Yukon Game Farm	• information, sale of animals	• sales 300.0	• 30,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
• Aquaria	• Vancouver Public Aquarium	• education, information, recreation		• 959,539 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Aquarium de Montréal	• education, information		• 355,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Aquarium du Québec	• education, information		• 290,000 visitors		Canadian Association of Zoological Parks and Aquariums 1991
	• Aquarium et Centre Marin de Shippegan	• viewing, education	• revenue 443.6 • estimated expenditure per person $8.53	• public education • increased knowledge of commercial species • 52,000 visitors	smaller	LeBreton 1991 (p.c.)
• Germplasm/ Seed Banks	• Plant Gene Resources of Canada (Ag. Can)	• Gene Pool		• 91,000 seed samples		Marriage 1992 (p.c.)
• NGO Environmental Groups	• cultural - psychological & recreational	• education, advocacy, awareness, management	• estimated 50,000 in memberships & public donations	• about 1,000,000 members	smaller	McAllister 1992 (p.c.)
	• Green Peace Canada	• awareness, advocacy, conservation		• approx. 380,000 members	n/a	McAllister 1992 (p.c.)
	• World Wildlife Fund	• awareness, advocacy, conservation		• approx. 50,000 donors	n/a	McAllister 1992 (p.c.)

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
• NGO Resource Management Agencies						
	• Ducks Unlimited, Canada	• resource management, education, interpretation, co-operative ventures	revenue: 47,900	• major conservation activities independently and co-operatively	greater - 75% of revenue from U.S. sources	Ducks Unlimited Canada 1990
	• Nature Conservancy of Canada	• conservation		• conservation of wetlands and other areas • land purchasing agent for governments		Francis 1991 (p.c.)
	• Nature Trusts	• conservation		• identification of areas in need of conservation • management plans		Whiting (in-house calculation); Erickson 1992 (p.c.)
	• Wildlife Habitat Canada	• conservation of landscapes and habitat		• landscape feature conservation • working with different levels of government, owners, and industry • habitat status reports	smaller	Neave 1992 (p.c.)
• Educational Institutions				• increased knowledge and understanding of the natural, social, economic and cultural values and relationships of biological resources • increased interest and insight into ecological and environmental matters		Whiting (in-house calculation)
	• University of Victoria	• education, research		• student appreciation of need for conserving biodiversity • economic and medicinal species benefits • students in biology, biochemistry, microbiology, environmental studies, geography and related courses in anthropology & psychology: 8690 • teachers and researchers in these areas: 65	smaller	Matheson 1991 (p.c.)

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
	• Université du Québec à Chicoutimi	• education, research		• recognition of research activities by the community • increased student interest leads to higher financing • undergrad course enrolment in biology and environment: 110 • graduate enrolment in renewable resources: 28 • number of professors: 16	smaller	Cloutier 1991 (p.c.)
	• Technical University of Nova Scotia	• education, research		• greater awareness of need for balance between agricultural and environmental communities • research leads to new areas of endeavour • 11 undergrad students • 18 graduate students • 6 professors		Watts 1991 (p.c.)
	• Université de Moncton	• education, research		• increased communication between university staff and the general public • environmentally oriented biology program: 138 students; 10 professors		Mallet 1991 (p.c.)
	• University of Toronto	• education, research		• 2,627 students enroled in agriculture and biological sciences • 83 teachers and researchers in biological sciences		Lang 1991 (p.c.)
	• University of New Brunswick	• education, research		• 28 faculty • 424 undergrads • 15 masters • 16 Ph.D. students		Mason 1991 (p.c.)
	• Memorial University	• education, research		• 66 academic staff members • 2703 undergrads • 76 graduate		Visentin 1992 (p.c.)

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY						
SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
	• University of Windsor	• education, research		• 530 undergraduate biology students • 25 grad students • 19 faculty members		Robertson 1991 (p.c.)
	• Institute of Urban & Environmental Studies, Brock University	• education, research		• 3 dedicated faculty • 250 undergrads		Middleton 1992 (p.c.)
	• University of British Columbia	• education, research		• 500 related undergraduates • 200 related graduates • 10 faculty focusing on biodiversity		Binkley 1991 (p.c.)
	• University of Manitoba	• education, research		• 92 related undergraduate and graduate degrees conferred in 1990-91 • 243 staff members in related disciplines		Gardner 1992 (p.c.)
	• University of Guelph	• education, research		• 2,300 undergrads in biological science • 800 undergrads in agriculture • 400 veterinary medicine students • 100 teachers/researchers in College of Biological Science • 160 teachers/researchers in Ontario Agricultural College • 120 teachers/researchers in Ontario Veterinary College		Segal 1992 (p.c.)
	• Simon Fraser University	• education, research		• 5,000 enroll annually • 188 graduate students • 40 faculty • 5 lab instructors • 17 technicians • 8.5 office & admin staff		McKeown 1992 (p.c.)
	• Université Laval	• education, research		• 1,393 students in biological sciences • 215 professors • 171 researchers		Tessier 1992 (p.c.)

APPENDIX 11 WORKSHEET OF ANNUAL BENEFITS RESULTING FROM USE/EXISTENCE OF BIODIVERSITY

SITE/SPECIES	MAJOR CLASSES OF FUNCTIONS	SPECIFIC USES OF BIODIVERSITY	MONETIZED BENEFITS ($000)	NON-MONETIZED BENEFITS	OUT OF COUNTRY BENEFITS	REFERENCES
	• Trent University	• education, research		• 15 faculty • approx 1,000 student courses in biology • approx 600 student courses in environmental and resource studies		Barrett 1992 (p.c.)
	• University of Western Ontario	• education, research		• approx 2,272 undergrad biology science students • 7 faculty		Haines 1992 (p.c.)
	• McGill University	• education, research		• 400 teachers and researchers • 1,250 undergraduate • 380 masters • 212 doctorate		Richard 1992 (p.c.)
Institutions: National	• National Film Board	• education • exposure to importance of ecosystems and biodiversity	revenue from completed films: 515	• exposure to Canadian wildlife and ecosystems, cultural diversity • income opportunities for film companies	smaller	Charbonneau 1992 (p.c.)
Federal Departments	• Agriculture Canada	• Revenues from Contracting-in and cost recovery for R&D in Biotechnology	1,312,000	• Canadian employment • Canadian technology development		Industry, Science and Technology Canada 1990
	• Energy, Mines and Resources Canada	• Revenues from Contracting-in and cost recovery for R&D in Biotechnology	127,000	• Canadian employment • Canadian technology development		Industry, Science and Technology Canada 1990
	• Fisheries and Oceans	• Revenues from Contracting-in and cost recovery for R&D in Biotechnology	30,000	• Canadian employment • Canadian technology development		Industry, Science and Technology Canada 1990
	• National Research Council	• Revenues from Contracting-in and cost recovery for R&D in Biotechnology	340,000	• Canadian employment • Canadian technology development		Industry, Science and Technology Canada 1990

APPENDIX 12: MEASURES AND COSTS OF CONSERVING BIODIVERSITY

SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
INSTITUTIONS: Zoological	Valley Zoo Edmonton, Alberta			budget 1,597,800		Leeb 1991 (p.c.)
	Assiniboine Park Zoo			2,655,000		Roots 1991 (p.c.)
	Calgary Zoo, Botanical Garden and Prehistoric Park			budget 10,000,000 capital 600,000		Canadian Association of Zoological Parks and Aquariums 1991
	West Edmonton Mall Game Farm			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Alberta Wildlife Park			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Kamloops Wildlife Park			budget 375,000 capital 100,000		Canadian Association of Zoological Parks and Aquariums 1991
	Okanogan Game Farm Ltd.			budget 100,000 capital 50,000		Canadian Association of Zoological Parks and Aquariums 1991
	Stanley Park Zoological Gardens			budget 950,000 capital 2,500,000		Canadian Association of Zoological Parks and Aquariums 1991
	Crystal Garden			1,000,000		Canadian Association of Zoological Parks and Aquariums 1991
	Wild Kingdom Zoo			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Grouse Island Park-Zoo			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Thompson Zoo			budget 120,000 capital 120,000		Canadian Association of Zoological Parks and Aquariums 1991
	Magnetic Hill Zoo			350,000		Canadian Association of Zoological Parks and Aquariums 1991
	Cherry Brook Zoo			160,000		Canadian Association of Zoological Parks and Aquariums 1991
	Oaklawn Farm			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Upper Clements Wildlife Park			119,000		Canadian Association of Zoological Parks and Aquariums 1991

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	Bowmanville Zoological Park			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Killman Zoo			80,000		Canadian Association of Zoological Parks and Aquariums 1991
	African Lion Safari and Game Farm			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	The Tortoise Farm			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Northern Frontier Zoo			budget 190,000 capital 3,000		Canadian Association of Zoological Parks and Aquariums 1991
	Storybrook Gardens			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Pheylonian Animal Haven			budget 24,000 capital 16,000		Canadian Association of Zoological Parks and Aquariums 1991
	Jungle Cat World Inc.			budget 300,000 capital 50,000		Canadian Association of Zoological Parks and Aquariums 1991
	Ken Jen Petting Zoo			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Riverview Park and Zoo			budget 515,344 capital 90,000		Canadian Association of Zoological Parks and Aquariums 1991
	Reptile Breeding Foundation (The Exotarium)			254,000		Canadian Association of Zoological Parks and Aquariums 1991
	Greenview Aviaries-Game Farm			120,000		Canadian Association of Zoological Parks and Aquariums 1991
	Colasanti Tropical Gardens			n/a		Canadian Association of Zoological Parks and Aquariums 1991
	Chippewa Wildlife Exhibit			budget 70,000 capital 50,000		Canadian Association of Zoological Parks and Aquariums 1991
	Metropolitan Toronto Zoo			budget 23,000,000 capital 4,000,000		Canadian Association of Zoological Parks and Aquariums 1991

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Ocean Park Ltd.			budget 110,000 capital 10,000		Canadian Association of Zoological Parks and Aquariums 1991
	Jardin zoologique de Bonaventure			150,000		Canadian Association of Zoological Parks and Aquariums 1991
	Jardin zoologique de Québec			budget 1,500,000 capital 200,000		Canadian Association of Zoological Parks and Aquariums 1991
	Société zoologique de Granby Inc.			421,680		Société Zoologique de Granby, Inc. 1991
	Parc safari africain (Québec) Inc.			budget 4,000,000 capital 300,000		Canadian Association of Zoological Parks and Aquariums 1991
	Centre naturanimo vallée de la Matapedia Inc.			budget 79,209 capital 8,000		Canadian Association of Zoological Parks and Aquariums 1991
	Zoo sauvage de St.-Felicien			2,800,000		Canadian Association of Zoological Parks and Aquariums 1991
	Forestry Farm Zoo			budget 720,000 capital 1,000,000		Canadian Association of Zoological Parks and Aquariums 1991
	Yukon Game Farm Ltd.			budget 300,000 capital 250,000		Canadian Association of Zoological Parks and Aquariums 1991
INSTITUTIONS: Aquaria	Vancouver Public Aquarium			budget 7,018,000 capital 7,750,000		Canadian Association of Zoological Parks and Aquariums 1991
	Aquarium de Montréal			1,300,000		Canadian Association of Zoological Parks and Aquariums 1991
	Aquarium et centre marin de Shippegan		700,600			LeBreton 1991 (p.c.)
	Aquarium du Québec			budget 1,116,800 capital 500,000		Canadian Association of Zoological Parks and Aquariums 1991

APPENDIX 12: MEASURES AND COSTS OF CONSERVING BIODIVERSITY

SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
INSTITUTIONS: Nature Centres	Shuswap Lake Provincial Park Nature House		12,000			Enns 1991 (p.c.)
	Kortright Centre for Conservation			1,100,000		Burchett 1991 (p.c.)
	Shubenacadie Wildlife Park		511,600			Vissers 1991 (p.c.)
	Salmonier Nature Centre		260,000			Jarvis 1991 (p.c.)
	Waskasoo Park Nature Centre		243,700			Robertson 1991 (p.c.)
	Cowichan and Chemainus Valleys Ecomuseum Society			390,985		Wood 1991 (p.c.)
	Saskatchewan Fish Culture Station		378,000			Fisher 1991 (p.c.)
INSTITUTIONS: Herbaria	University of British Columbia Herbarium			n/a		Straley 1991 (p.c.)
	University of Guelph Arboretum			565,000		Ronald 1991 (p.c.)
	Memorial University Botanical Garden			360,000		Jackson 1991 (p.c.)
	Allan Gardens Conservatory		261,000 yearly operating expenses			Powers 1992 (p.c.)
	Butchart Gardens			n/a		Clarke 1991 (p.c.)
INSTITUTIONS: Museums	Provincial Museum of Alberta		4,000 museum budget			McGillivray 1992 (p.c.)

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Sandilands Forest Centre Museum			11,390		Beaven 1991 (p.c.)
	Whiteshell Natural History Museum			4,500		Clarke 1991 (p.c.)
	B.J. Hales Museum, Brandon University			29,000		Letkeman 1991 (p.c.)
	Royal Ontario Museum • ornithology dept. • entomology • invertebrate zoology • botany • mammalogy			 5,000 12,975 36,000 24,000 384,100		DeCarlo 1992 (p.c.); Robertson 1991 (p.c.).
	Canadian Museum of Nature		11,093,000			Government of Canada 1991d
	Manitoba Museum of Man and Nature			2,450,400		DeCosimo 1991 (p.c.)
	Langley Centennial Museum and National Exhibition Centre			3,290		Thorpe 1992 (p.c.)
	Redpath Museum, McGill University			0		Pasztor 1991 (p.c.)
INSTITUTIONS: Universities	University of Victoria: • cost per student • operating costs for departments specified (excluding salaries) • capital equipment for same			 4,500 1,214,000 350,000		Matheson 1991 (p.c.)

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Université du Québec à Chicoutimi: • teaching • operation of undergrad labs • equipment rental of same • research support • total cost • cost per student			1,100,000 212,500 50,000 165,000 1,527,500 11,068		Cloutier 1991 (p.c.)
	Université du Québec à Montréal: • biological science operating expenses • forest ecology research • health and environment studies (CINBIOSE) • laboratory of environmental toxicology (TOXEN) • environmental research chair			7 401 740 496 734 1 122 644 630 058 356 601		Corbo 1991 (p.c.)
	Technical University of Nova Scotia: • operating budget • capital • research			550,000 6,500 300,000		Watts 1991 (p.c.)
	Université de Moncton: • operational budget (Biology Dept) • research budget			180,000 1,000,000		Mallet 1991 (p.c.)
	University of Toronto: • cost per student			11,967		Lang 1991 (p.c.)

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Institute of Urban and Environmental Studies, Brock University			n.a.		Middleton 1992 (p.c.)
	Memorial University • cost of Biochemistry Section • cost of Biology Section			8,832,000 2,604,000		Canadian Association of Zoological Parks and Aquariums 1991
	University of New Brunswick • Financial expenditures, Biology Department • Sponsored Research			2,527,000 957,328		Mason 1991 (p.c.)
	University of Manitoba • operating expenses			25,279,199		Gardner 1992 (p.c.)
	University of Windsor • costs incurred by the Faculty of Biology			3,052,500		Robertson 1991 (p.c.)
	University of British Columbia • cost per student • Potential research at the Centre for Applied Conservation Biology			3,000-5,000 1,700,000		Binkley 1991 (p.c.)
	University of Guelph			80,000,000		Segal 1992 (p.c.)
	Simon Fraser University			500,000		McKeown 1992 (p.c.)
	McGill University • research in biodiversity • annual costs per student: - undergrad - masters - doctorate			55,000,000 8,000 12,000 28,000		Richard 1992 (p.c.)

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
INSTITUTIONS: Nongovernmental Resource Management Agencies	Nature Conservancy of Canada			2,500,000		Francis 1991 (p.c.)
	Ducks Unlimited			48,454,000		Ducks Unlimited Canada 1990
	Nature Trust of British Columbia • land acquisition • database, other expenses			642,000 440,000		Erickson 1992 (p.c.)
	Wildlife Habitat Canada			4,000,000		Neave 1992 (p.c.)
INSTITUTIONS: Non-Government Interest Groups	World Wildlife Fund			(approx) 6,000,000		McAllister 1992 (p.c.)
	Canadian Parks and Wilderness Society			(approx) 800,000		Mosquin 1992 (p.c.)
	Sierra Club Canada			40,000		Mosquin 1992 (p.c.)
	Other Canadian Associations and Environmental interest groups (approx. 2,000)			estimated 6,000,000		Whiting (in-house calculation)
INSTITUTIONS: National Parks	1990/91 expenditures for operations capital		134,500,000 57,000,000			Hartley 1992 (p.c.)

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Newfoundland and Labrador		3,200,000			Dept. of Environment and Lands 1992 Whiting (in-house calculation)
	Prince Edward Island	negligible amount spent on conservation of biodiversity				Murray 1992 (p.c.)
	Nova Scotia					
	New Brunswick		8,475,000			Tait 1991 (p.c.)
	Quebec (includes Fish and Wildlife also) • salary • operations • capital • transfers		 100,547,200 49,110,600 11,542,300 70,545,700			Morin 1992 (p.c.)
	Ontario • Nature Reserves • Natural Environment • Wilderness		 20,541 13,751,080 957,265			Ontario Ministry of Natural Resources 1991a; Marriage 1992 (p.c.); Ontario Ministry of Natural Resources 1991b
	Manitoba					
	Saskatchewan		7,152,720			Crouter 1991 (p.c.)
	Alberta					
	British Columbia • cost to provincial government of parks		33,391,000			Eastman 1992 (p.c.)
Territorial Parks	Yukon Territory: Herschel Island and Coal River Springs		O and M 277,000 capital 23,900			Fuller 1992 (p.c.)

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Northwest Territories		capital 1,200,000 O and M 800,000 • only some of these devoted to biodiversity			Lloyd 1992 (p.c.)
Provincial Forests	British Columbia		3,198,000			Eastman 1992 (p.c.)
INSTITUTIONS: Public Service, Federal	National Research Council (1989-90):					Industry, Science and Technology Canada 1990; Government of Canada 1990c.
	• biotech research, extramural		5,438,000 66,536,000			
	• biotech research, intramural		26,963			
	• CISTI		3,283,000			
	• Industrial Research Assistance Program					
	Natural Sciences and Engineering Research Council (1989-90):					
	Networks of Centres of Excellence		1,000,000			Government of Canada 1991f
	• Operating Grants					
	- Agriculture		21,547,000			
	- General Nature		8,140,000			
	- Life Sciences		3,830,000			
	- Exploration and Exploitation		31,363,000			
	• Strategic Grants					
	- Biotechnology		1,479,000			
	- Food, Agriculture, Aquaculture		2,334,000			
	- Forestry		702,000			
	- Oceans and Inland Waters		536,000			
	- Environmental Quality		3,091,000			
	• Scholarships (total including engineering)		67,000,000 (about half of the scholarship fund)			
	• Biotechnology University-Industry Program		2,745,000			Industry, Science and Technology Canada 1990

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Fisheries and Oceans:					
	• Salmonid Financing		(Fed) 42,500,000 (B.C.) 1,700,000			Government of Canada 1991d; Fisheries and Oceans 1990.
	• Biological Services		102,846,000			
	• Atlantic Fisheries					
	- habitat management		69,401,000			
	- resource and industrial dev.		36,632,000			
	Pacific and Freshwater Fisheries					
	- fisheries and habitat dev.		53,430,000			
	- resource and industrial dev.		39,311,000			
	• Capital Expenditures					
	- Science		10,917,000			
	- Atlantic Fisheries		4,766,000			
	- Pacific/Freshwater Fisheries		7,943,000			
	• AQUATECH Network		25,000			Industry, Science and Technology Canada 1990

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	Forestry Canada:					Government of Canda 1991e
	Graduate Supplement Program		350,000			
	Provincial contribution to research		43,800,000			
	• Forestry Research		54,445,000			
	- forest production		9,000,000			
	- biotechnology		2,900,000			
	- IFM systems		2,500,000			
	- forest protection		13,500,000			
	- (pinewood nematod)		400,000			
	- environmental research		5,500,000			
	- forest utilization		8,200,000			
	Operation (regional establishments and institutions)		14,000,000			
	- forestry services		6,500,000			
	• Education					
	- Newfoundland forestry youth training program		3,000,000	industry CEIC 1,100,000		
	- South Moresby Replacement		(50:50 Fed:Prov) 2,300,000			
	- forest industry intern program		440,000	industry/EICFC 440,000 industry 502,500		
	- forest management (silviculture, protection, etc.)		Fed: 225,800,000 Prov: 1,287,800			
	• Grants and Contributions		125,129,333			
	- FORINTEK		9,150,000			
	- FERIC		4,500,000			

APPENDIX 12: MEASURES AND COSTS OF CONSERVING BIODIVERSITY

SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Indian and Northern Affairs: Resource Management (trapper training, forest)		34,519,000			Government of Canada 1991b
	• Environmental Management		2,343,000			
	• Job Training		825,000			
	• Grants					
	- coordinated northern scientific activities		130,000			
	- university scient. research		748,000			
	- outstanding awards		5,000			
	Agriculture Canada (87-88):					Government of Canada 1991b
	• Resource Research		22,970,000			
	• Animal Research		39,273,000			
	• Crop Research		116,820,000			
	• Food Research		16,880,000			
	• BIOCROP, BIONIF and BIONET		37,500			
	• Centre for Land and Biological Resources Research		5,951,100			Industry, Science and Technology Canada 1990
	IBPGR Plant Genetic Research		500,595			Rice 1992 (p.c.)
	• Cdn donations 1990					
	Energy, Mines and Resources Canada (CANMET)					Industry, Science and Technology Canada 1990
	• Bio-leaching		142,000			
	• Bio-Absorption		163,000			
	• Destruction		26,000			
	• Environmental		284,000			
	• Effluent Treatment		40,000			

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Energy, Mines and Resources Canada- Energy Research Laboratories					Industry, Science and Technology Canada 1990
	• Microbial Plugging of Oil Reservoirs		Government 200,000			
	- Coal Research Laboratories		Industry 200,000			
	• Microbial methane degradation		30,000			
	Environment Canada (88-89):					
	• Inland Water Conservation		98,791,000			Government of Canada 1991c
	• Wildlife Conservation		37,125,000			
	• Environmental Protection		65,819,000			
	- grants for conservation and protection		(3,030,822)			
	- contributions		(15,613,880)			
	• Operating costs		238,769,000			
	• BIOQUAL Network		25,000			
	• Grants and contributions, transfer payments		24,884,975			
	• Wastewater Technology Centre		Government 413,000 External 276,000			Industry, Science and Technology Canada 1990
	• National Waters Research Institute		87,000			
	• (Environmental Protection-Quebec Region)		(239,000)			
	• (1990/91 National Parks budget)		(191,500,000)			

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Health and Welfare Canada; Drugs Directorate - Bureau of Drug research					Industry, Science and Technology Canada 1990
	• Biotechnology research		56,000			
	• BIONET		25,000			
	Bureau of Biologics					
	• Biotechnology activity		600,000			
	Laboratory Centre For Disease Control		529,500			
	Food Directorate		25,000			
	Environmental Health Directorate		576,800			
	National Defence • Biotechnology Activity		380,000			Industry, Science and Technology Canada 1990
	Industry, Science and Technology Canada; Biotechnology					Industry, Science and Technology Canada 1990
	• Industry and Technology Sector		2,600,000			
	• Policy Sector		11,734,000			
	Medical Research Council • Biotechnology Grants and Training		41,514,000			Industry, Science and Technology Canada 1990
	International Development Research Centre • Biotechnology Activities in Canada		938,400			Industry, Science and Technology Canada 1990

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
	Western Economic Diversification Canada • National Agricultural Biotechnology Initiative		25,000,000			Industry, Science and Technology Canada 1990
	National Film Board		5,700,000 production costs of finished films			Charbonneau 1992 (p.c.)
Institutions: Public Service	• Fish and Wildlife Management for Conservation					
	Newfoundland		5,750,000			Curnew 1991 (p.c.)
	Prince Edward Island		393,500			Callaghan 1992 (p.c.)
	Nova Scotia					
	New Brunswick		8,530,000			Tait 1992 (p.c.)
	Quebec		see provincial parks (above)			Morin 1992 (p.c.)
	Ontario					
	Manitoba					
	Saskatchewan		26,959,000			Crouter 1991 (p.c.)
	Alberta		23,670,000			Government of Alberta 1991; Murray 1992 (p.c.)
	British Columbia • Wildlife • Fisheries • Enforcement		 10,020,000 14,486,000 7,592,000			Eastman 1992 (p.c.)

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
Territorial	Yukon					
	Northwest Territories		O and M approx. 22,500,000 capital 741,000			Lloyd 1992 (p.c.)
Provincial, Other Expenses	Alberta					
	• Environmental Protection, Enhancement, and Research (88/89)		19,924,000			
	• Environmental Council of Alberta (88/89)		798,000			
	• Forestry, Lands and Wildlife (89/90)					
	- Public Lands Management		19,669,000			
	- Forest Service		80,753,000			
Canada	North American Waterfowl Management Plan		60,000,000			Government of Canada 1992

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SITES/SPECIES/ INFRASTRUCTURE	MEASURES TO BE UNDERTAKEN	ESTIMATED TOTAL COST OF MEASURES (current and unmet, $000)	CURRENT NATIONAL EXPENDITURE	CURRENT EXPENDITURE — BILATERAL, MULTILATERAL, AND NGO/PRIVATE	UNMET COSTS ($000)	REFERENCES
Green Plan Initiatives	• to be spent over five years					
	Clean Air, Water and Land	850,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991.
	Sustaining Renewable Resources	350,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991
	Special Spaces and Species	175,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991
	Arctic Stewardship	100,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991
	Global Environmental Security	575,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991
	Environmentally Responsible Decision-making	500,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991
	Environmental Assessment and Audits	275,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991
	Emergency Preparedness	175,000				Government of Canada 1990; Canadian Centre for Biodiversity 1991
Infrastructure: Other	Human Resource Development • Ecologists • Resource Managers • Biologists • Economists • Environmental Engineers • Integrating Environmental Studies • Supporting and associated disciplines	37,000				Power and Follett 1987
	Research on status of Biodiversity • ecological • socio-economic	? annual 1,000				

APPENDIX 13

METHODS AND METHODOLOGICAL CONSIDERATIONS IN ASSESSING MONETARY VALUES OF CANADA'S BIODIVERSITY

This appendix presents some information on the methods and methodological considerations used in the preparation of the economicd section of *Canada's Biodiversity*. It is included to help explain some of the approaches used in the derivation of economic figures in the report. Information is given on the overall approach adopted, and the specific methods with respect to benefits and costs.

1. OVERALL APPROACH

There were essentially five steps involved in the preparation of the economics component of Canada's biodiversity study:

1. defining a framework for benefit inclusion (since benefits were originally perceived as being difficult to estimate);
2. gathering information on the benefits derived from Canada's biological resources;
3. gathering information on the costs of current efforts and activities to conserve biological resources;
4. helping to define new measures to conserve biological resources over and above those identified in Canada's Green Plan, and estimating the costs of these measures; and
5. presenting the information collected.

A number of overall points are worth indicating at the start of this section:

The UNEP International Advisory Team of Experts suggested a number of changes to the original guidelines for the Country Studies. This team perceived the economics component in a context broader in scope than that originally suggested by UNEP. The UNEP guidelines related benefits of biodiversity conservation efforts directly to costs, on a program-by-program basis; the team of experts believed that a more holistic approach to the definition of benefits from biodiversity was required. This broader view would then provide the context and/or the definition for the overall benefits derived from biodiversity within which individual programs could be evaluated.

By adopting this approach, two important changes were made in the approach to the estimation of benefits associated with biodiversity:

1. The estimation of benefits now was *not* tied to specific measures of conservation being undertaken (existing or proposed); and
2. The "benefits of biodiversity" were changed from an analysis of *changes* in biological diversity, to an analysis of *benefits* derived from biological resources.

This second change was especially significant, since it changed the analysis from being, in economic terms, a "marginal analysis" (more concerned with *changes in diversity*) to a "gross analysis" (more concerned with *total values*). By attempting to estimate the value of biodiversity in total (i.e. value of biological resources), the *relative* value of particular measures or all proposed measures can be determined. The relationship between the proposed conservation measures benefits and total benefits is important in that it shows the extent to which values are being preserved or require conservation because they may be at risk. However, both changes in approach to the estimation of benefits derived from biodiversity represent significant departures from the original UNEP guidelines.

The accounting method for the production processes used to generate the farm gate values, forest timber values, and fish landed values neglects many important aspects of the technology being applied to commercial production. The generation of large values from commercial agricultural production, for example, masks the fact that the capital base of the monoculture farmer may be physically eroding beneath him.[1] In the same way that traditional national economic accounts ignore the resource base, so too does the established accounting for commercial resource-based production. There is no accounting mechanism that currently reflects the long-term effects of soil degradation, erosion, lost water quality, and other negative effects of some agricultural practices (except in the short term by high fertilizer costs, irrigation costs, etc.). More significantly, there is no way for the benefits of proper resource stewardship to be reflected in the income/accounts of those who are adopting such practices. While it is not the intent of this paper to digress into policy areas, it should be noted that only when production techniques that conserve the resource base can be shown to be financially viable, or capable of producing superior products, will such techniques become common practice. Incentives for such production and resource management techniques, or a different economic policy framework

[1] Monoculture farming practices can lead to soil degradation. For example, see "Monoculture", by J.F. Power and R.F. Follett, *Scientific American* Vol. 256, No. 3.

that reflects these values (retained or lost), may be required. The amount of these incentives can then be viewed as a cost associated with the conservation of biological resources. The benefits derived from such measures must, at least equal these incentives or be greater in the long term. The question of the distribution of the benefits and costs associated with such measures helps determine the appropriate policy framework and inducements.

There are many new techniques or changes in methods of production that could contribute to the maintenance of biodiversity. For example, reduced use of herbicides and pesticides in agricultural and forestry production processes may reduce human health effects or wildlife losses related to these agents, while conserving biological resources. Other examples abound. The benefits and costs of such activities or changes have not generally been captured in this report, primarily due to the approach taken for the estimation of benefits. A limitless number of different scenarios for a wide variety of production processes or resource management techniques could be examined and assessed for their net contribution to the conservation of biodiversity and/or positive effects on the human environment. However, each of these must be assessed on an individual policy, program or project level. While such assessments are possible, it has not been the purpose or mandate of this paper to conduct this kind of analysis here.

Resource management techniques that preserve biological diversity could result in either increased net benefits or fewer net benefits; further analysis on a case-by-case basis is required if any useful information is to be derived from this area of concern.

The perspective of time tends to be lost in this analysis: current costs are identified for streams of benefits that extend far into the future. For example, the investment made in human resource development by training and educating ecologists, economists, resource managers, and others who will understand and appreciate the need for biological diversity conservation, will yield benefits and assure Canada's competitiveness in years later—frequently at an indeterminate time.

2. BENEFITS

The perceived benefits of biological resources are perhaps self-evident: they contribute to virtually all aspects of our existence and provide the basis for the majority of our industry. The actual measuring of these benefits must be accomplished using both quantitative and qualitative approaches. A first step was to provide an overall framework that allowed the identification of uses.

2.1 BIOLOGICAL RESOURCES AND THEIR BENEFITS

Sources of benefits were developed and are presented in the following major groupings:

1.0 Plants
  1.1 Wild
    1.1.1 Forest trees
    1.1.2 Crops (fruits, wetland produce, etc.)
    1.1.3 Grazing
    1.1.4 Pharmaceuticals
    1.1.5 Other (aquatic, tundra, desert, other forest, non-forest, etc.)
  1.2 Cultivated
    1.2.1 Forest plantations
    1.2.2 Agricultural crops
    1.2.3 Horticultural (flowers, sod, shrubs, etc.)

2.0 Animals
  2.1 Wild
    2.1.1 Wildlife-related recreation
    2.1.2 Fishing (commercial, recreational)
    2.1.3 Trapping

      - 2.1.4 Other (insects, worms, etc.)
  - 2.2 Domesticated
    - 2.2.1 Agriculture
      - 2.2.1.1 normal agriculture
      - 2.2.1.2 fur farming
      - 2.2.1.3 game ranching
      - 2.2.2 Aquaculture
      - 2.2.3 Other (pets, scientific specimens, etc.)

- 3.0 Micro-organisms
  - 3.1 Wild
  - 3.2 Cultured
    - 3.2.1 Yeasts
    - 3.2.2 Bacteria for vaccines, medication
    - 3.2.3 Bacteria for agriculture, dairy products

- 4.0 Ecosystems
  - 4.1 National Parks/Reserves (all national parks, reserves, wildlife refuges, etc.)
  - 4.2 Provincial Parks
    - 4.2.1 Nature Reserves
    - 4.2.2 Natural Environment Parks
  - 4.3 Ecological Reserves, Wildlife Refuges
  - 4.4 Public Protected Areas (Natural Environment Areas, Designated Areas, Conservation Areas
  - 4.5 Private/NGO Protected Areas (Ducks Unlimited, Waterfowl Parks, Game Reserves
  - 4.6 Other (Natural Landscapes, Eco-tourism, Eco-art)

- 5.0 Institutions
  - 5.1 Museums
  - 5.2 Herbaria
  - 5.3 Botanical Gardens
  - 5.4 Aquaria/Aviaries
  - 5.5 Zoos
  - 5.6 Germplasm/Seed/Gene Banks
  - 5.7 Microbial Culture Collections
  - 5.8 Data Banks
  - 5.9 Other Research Institutions

2.2 CONCEPTUAL PROBLEMS

In attempting to estimate the benefits of biological resources, a number of conceptual (and practical) problems were encountered, including:

- the difficulty in identifying *all* known specific uses of biological resources and, therefore, *all* values in question;
- the availability and compatibility of current data; including overall quality of data and the likelihood of multiple counting of the same value;
- consistency in point of view of valuation (evaluation perspective): Whose economic perspective is being used? Is this consistent throughout the valuation? The maintenance of a consistent perspective of valuation is important: differentiation between benefits and costs is not always apparent;
- the extent of valuation—primary *and/or* secondary values/benefits; direct, indirect and/or induced economic benefits; or some mix of all these;
- the treatment of commercial agricultural/forestry/aquaculture value figures when these industries frequently are the basis of lost biodiversity;
- methodological inadequacies for measuring certain values (especially optional use, existence values);
- the treatment of negative benefits resulting from biodiversity (health costs, productivity losses, etc.);
- the treatment of bio-engineering and bio-technology benefits when these are created sometime in an uncertain future;
- short-term market aberrations that seriously distort commodity market prices indicating zero or negative returns to certain commodity production or unusually high commodity values;

- the relatively unequal treatment of primary benefits associated with biodiversity in non-commercial sectors (recreation, ecosystem functions, etc.) compared with the large and generally well documented benefits associated with commercially exploited biological resources (agriculture, fisheries);
- the attribution of benefits to resources and/or industrial sectors beyond the primary benefit level. Although it may be appealing to attribute the value of all agricultural and food industries to the basic biological resources, it would be incorrect to do so. In this study we attempt to provide values that are primary in nature. For example, in industries such as agriculture, the value estimated will be the farm gate price/value, or in the case of forestry, the value of shipments from saw and planing mills. These values are closest to the primary values used in other areas of valuation. Too many other factors of production (attribution problems) are incorporated into the final values of goods sold at the retail level.
- the treatment of illegal use of biological resources: only those benefits and costs associated with the *legal* trade/use of the resources are contained in the figures presented (i.e. things such as peregrine falcon or marijuana sales are not included).

2.3 METHODOLOGY

Canadian officials, with the assistance and support of officials from several other countries, devised a worksheet to help incorporate benefits into the assessment of the current status of biodiversity. This worksheet was used to identify and quantify the magnitude of the benefits derived from biological resources in Canada within a one-year period. In this study, an attempt has been made to use 1990 as the base year, although consistency was not always possible. The column headings used in the Appendix 11, and a brief description of their meaning are as follows:

SITE/SPECIES – four major headings were used to organize this information: plants, animals, micro-organisms, and ecosystems. The latter heading is a bit of a misnomer in that institutions were also included (museums, herbaria, aquaria, nature centres, educational institutions, etc.). By expanding this class, all sources of benefits from biological resources were included in the analysis.

MAJOR CLASSES OF FUNCTIONS - this column was used to indicate a general class of function of the resource. It included those functions such as commercial, subsistence, cultural and psychological, scientific, and recreational.

SPECIFIC USES OF BIODIVERSITY - within each major class, more specific uses were identified to which values could be attributed. Examples of these included hunting, fishing, harvesting, travel for nature, scientific specimens, optional future use and existence.

MONETIZED BENEFITS - where monetary values associated with specific uses were available, these were identified and included in the analysis. Many different forms of monetized values were used, including: revenues, consumer surplus, net economic benefit, income, profit, net revenue, production value, etc. Due to the variety of responses and sources of information used to derive these monetized benefits, there was no way of ensuring the consistency of values presented. Monetized values excluded from the analysis were indirect and induced benefits (economic impacts) associated with expenditures.

NON-MONETIZED BENEFITS - in cases where no published monetized benefit figures were available, other indicators of benefit were employed. These were short, descriptive indicators that described the benefit being derived. Examples of these include: numbers of visitors to institutions, amount of employment created, numbers of students, ecological services (oxygen production, nutrient transfer, symbiosis, soil conditioning, etc.), and others.

OUT OF COUNTRY BENEFITS - this column was a relatively subjective assessment of the relative value of the benefits from specific uses that were derived outside the country. In some cases, fairly objective criteria established the relative proportion of benefits going to other countries: percent of a crop exported, for example; but in other cases, there was no clear basis for making such assessments and subjective estimates were used.

REFERENCE- this column identifies the source for the information, as well as present any calculations or assumptions made in the derivation of the figures presented. This column also provided a means for readers/reviewers to gain a sense of the reliability of the information being presented. At first glance, it may appear that there are omissions in the lists of benefits derived from biodiversity. Although there are indeed some real gaps in the data, some data have been omitted intentionally. As an example, the expenditure figures for participants who took part in recreational activities associated with wildlife incorporate values such as support outfitters, guides, special transportation services (boat, ferry, helicopter), and other expenditures. These values are inputs into the wildlife recreational experience. To identify each, and incorporate its value into the analysis would represent a double counting of benefits. The expenditures on these types of activities do generate a secondary impact in terms of their economic impact throughout the economy, but such benefits have been deliberately excluded from this study. Another example of values that appear to have been ignored are certain government revenues from activities such as sport fishing and hunting. In fact, these revenues are reflected in the expenditures reported by sports fishermen and hunters.

3. COSTS

The approach adopted for the examination of costs of biological resource conservation are described in this section.

3.1 SOURCES OF COSTS

Cost figures for the conservation of Canada's biological resources are derived in several ways; for the most part these are incurred by various levels of government, non-governmental organizations, and private companies.

In many cases, resource management for sustainable use is not necessarily an activity that supports biodiversity conservation, although it may do so as a consequence. For example, maximizing the sustainable yield of cod may result in depletion of other non-target fish or invertebrate populations. The objectives of various resource management organizations may actually be directed towards results other than biological diversity conservation, yet still contribute to the conservation objective incidentally. In this instance, to attribute costs associated with these other objectives to biodiversity can require a subjective interpretation that is perhaps not easily upheld using objective criteria. Yet, to ignore them would be equally erroneous.

3.2 CONCEPTUAL CONSIDERATIONS

While deriving the estimates of benefits from biodiversity presented a significant challenge, determining the costs related to the conservation of biological resources was not an appreciably easier task. In attempting to cost current activities of biodiversity conservation, many different factors should be taken into consideration. Some of the conceptual (and practical) problems associated with this costing exercise include the following:

- distinguishing between costs associated with the conservation of biological *resources* and those associated with the conservation of biological *diversity*;
- distinguishing between costs that are applicable and those that are non-applicable, because of factors such as program/project objectives, or activities/expenses related to conservation of biodiversity, but not specific to it;
- the inconsistency in the definition of cost components and their treatment in the analysis among different jurisdictions and organizations incurring costs for biological conservation.
- the treatment of different sources of funds: public, NGO, private, Canadian, foreign;
- concern for possible double/triple counting of expenditures (eg. flow through funding, grants, transfer payments, etc.);
- financial commitments versus actual expenditures;
- appropriate recognition, identification, and accounting of non-financial costs associated with conservation activities;
- the treatment of recurrent costs versus non-recurrent costs (especially concerning "Unmet Needs");
- the need to choose between possible cost options in conservation activity;
- the need for a consistent perspective of measuring costs/funding: as with benefit estimation, (for example, some organizations considered some funds from external contracts or grants as benefits, rather than costs);
- recognizing and determining the costs that private companies bear in curtailing certain practices, adjusting harvesting techniques or undertaking other actions that are aimed at the preservation of a public good (maintenance of biological diversity); and similar activities by NGOs;
- the treatment of different annual costs in a single estimate; i.e. program costs spread over a limited time horizon may include high initial costs and low ongoing costs. Depending on where in the program cycle the information is collected, an either high or low estimate may have been given. Total program/project costs (if they have a definable limit) should possibly be used rather than the "snapshot" being given now.
- taking into account all costs of biological conservation in the tables; (it is believed that the majority of such costs have been identified).

Deliberate changes, and even outright destruction, are often inflicted on biological resources through such means as pesticides, clear-cutting of forests and urban development. On the other hand, substantial amounts are expended in protecting and defending against certain biological agents, and in making repairs caused by biological resources. Disbenefits are generated from the effects of:

- bacteria/viruses/fungi
- insects
- small mammals/rodents
- large mammals
- plants

Examples of the type of expenditures incurred because of this biodiversity and its maintenance are:

- health costs (human and animal)
- health research (human and animal)
- lower human/animal productivity
- increased costs of production (fencing, machinery repairs, etc.)
- plant research
- anti-poaching/conservation services
- monitoring/controlling trade in endangered species (CITES)
- use of natural or manufactured herbicides and pesticides
- accidents caused by wildlife in air,

ground and water
- other expenditures

These disbenefits have not been estimated in this study; they are identified here in an effort to ensure that it is recognized that carte blanche conservation of biodiversity does not lead exclusively to the generation of benefits. Significant costs are also incurred.

Another important area that must be taken into consideration in assessing the net benefits associated with any new (or existing) measures designed to conserve biological diversity is the matter of "opportunity costs." When a conservation measure precludes the use of resources for any purpose, this results in the incurring of a potential opportunity cost. This cost reflects the value of benefits foregone by the preclusion of uses of the biological resources or by other resources being made inaccessible because of the conservation measures.[2]

Because of the highly aggregated nature of Canada's analysis of the status of biodiversity, it is not possible to estimate specific opportunity costs associated with conservation in this report. Opportunity costs are best examined on a specific case basis where concrete examples of alternative resource uses can be quantified and assessed.

3.3 METHODOLOGY

Similar to the benefits worksheet, a cost sheet that created the framework for the derivation of costs associated with the conservation of biodiversity, was also prepared.

The columns and their meanings in Appendix 12 are as follows:

SITES/SPECIES/INFRASTRUCTURE - because this sheet was used to present costs of current conservation efforts, very few site or species specific information was available. There was, however, information on the infrastructure and institutional costs. This column therefore mainly presented information on current conservation activities and their associated costs.

MEASURES TO BE UNDERTAKEN - this column provided a brief description of the measures of conservation being undertaken, and included such things as the names of institutions and organizations carrying out conservation activities.

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[2] Some potential developments or uses are obviously mutually exclusive: not all opportunity costs are additive.

ESTIMATED TOTAL COST OF MEASURES - this column presented the estimate of the total cost of proposed new measures to conserve biodiversity.

CURRENT NATIONAL EXPENDITURE - expenditures on biological conservation activities by the federal and provincial governments were included in this column.

CURRENT EXPENDITURE - BILATERAL, MULTILATERAL AND NGO/PRIVATE - expenditures on biological conservation activities by primarily non-governmental organizations and private companies or organizations were presented here. Due to the limited activities of bilateral and multilateral agencies in Canada, little information was available on their expenditures. Generally, Canada contributes to bilateral and multilateral agencies rather than being the beneficiary of their spending. The one notable exception is the North American Waterfowl Management Plan, which receives major funding from United States sources.

UNMET COSTS - this column indicated the difference between the amount needed (estimated total cost of measures) and the total of current expenditures from all sources.

REFERENCES - same as for benefits: the source of the information presented.

4. DATA COLLECTION

There are many organizations involved in the management and conservation of biological resources in Canada. Many have knowledge about the benefits being derived and the costs incurred by themselves and other similarly oriented organizations. These organizations span all levels of government, and also include private companies, individuals, societies, educational/research institutions, and other non-governmental organizations. For this study, material was gathered from secondary sources of information such as Statistics Canada and various government libraries. Extensive research was carried out in an attempt to collect all available relevant information. The List of Sources identifies individuals and organizations who supplied information, as well as reference material examined.

In addition, direct requests were made to all provincial and territorial governments. These requests identified information requirements including:

- benefits from provincial/territorial parks and public protected areas managed for the conservation of their resources (visitor expenditures attributable to parks, entrance fees and/or other revenues, consumer surplus, non-monetary benefits, number of visitors);
- costs incurred in the conservation and/or preservation of biological resources in these parks and public protected areas (capital costs, operations, maintenance, management);
- benefits of fish and wildlife management and conservation (monetary and non-monetary) and the costs incurred in undertaking such management programs (capital, operations, management, research);
- identification of all private, NGO or municipal areas managed primarily for conservation of biological resources;
- estimate of the extent of eco-tourism and its role and value as part of the provincial/territorial overall tourism sector.

Appropriate federal government departments were also identified and approached in order to obtain germane material.

Post-secondary educational institutions with biological or natural resource programs or courses were canvassed to determine the following;

- the number of students (undergraduate and graduate) currently enrolled in courses or programs in biological sciences or those related to biodiversity (for example such subjects as resource economics, environmental law, rural sociology and others that in some way relate to biodiversity and its conservation);

- the number of teachers and/or researchers currently engaged in teaching courses or programs in biological sciences or those related to biodiversity and its conservation;
- the costs incurred by the institution in the teaching and/or researching of biodiversity and its conservation (cost per student, capital/equipment costs, research costs, operations, management, etc.);
- the measures used to indicate the benefits associated with the institution's teaching or research concerning biodiversity, and what some of these benefits actually are.

Contact was also made with various museums, herbaria, aquaria, and zoological institutions in an effort to obtain the following facts:

- any benefits (monetary and/or non-monetary) realized from the conservation activities or what uses are made of the conserved resources
- the number of visitors to the museum/institution in 1990
- the number of these visitors who were Canadian and how many were from outside Canada;
- visitor expenditures on their trip/visit to the museum/institution, that were attributable to the museum in 1990 (entrance fees, other visit expenses (if available)
- how much the institution spent on its biological conservation activities (biological surveys, collections, research, publications, education) in 1990 (capital, operations, maintenance, etc.)

Discussions were held with officials from germplasm and seed banks, relevant national associations, other NGOs, and many private companies. In all, over 200 agencies, organizations, and individuals were approached with a view to collecting supporting information.

It is unfortunate that this study was conducted in December, a time of year when many agencies and institutions are not fully staffed because of the holiday season. As a result, only a small percentage of the requests were answered in time for inclusion in this report. It is hoped that more complete coverage can be incorporated in later updates of this report. While every effort was made to contact all those organizations making a contribution to the conservation of biological resources, it is possible that some may have been overlooked.

Another difficulty was encountered when, not infrequently, the institutions contacted for information on this component of the study indicated that they did not have information organized in such a manner as to permit an easy or prompt response. It was evident that the material was often organized in a format that would entail an extensive effort to extract the figures required for this study; several institutions replied that they were either unable or unwilling to make available the time and/or personnel needed for such an effort.

The whole topic of biodiversity and the economics related to it, covers an extremely broad cross-section of Canadian knowledge. In a number of instances, it was impossible to obtain relevant figures or to obtain figures that can be construed as reasonably accurate. Furthermore, in many of these cases, it is possible that information was not obtained because the most appropriate source was not identified, not that the information itself was non-existent. For example, on several occasions, individuals or organizations approached indicated that the information requested did not exist, when further research eventually produced the information.

An enormous variety of responses resulted from this extensive solicitation, ranging from short and precise figures corresponding to each item requested, to pages of material and thoughts and suggestions. It is evident that there is widespread concern for the subject of maintaining Canada's biodiversity and its economic significance.

As the material for this study was being compiled, it became apparent that different definitions were being used by the various organizations approached for information. Initially this was seen as a major problem and attempts were made to standardize the use of terms and values. In the latter stages of this study, however, it was recognized that severe time constraints would not permit the establishing of some uniformity in terms and figures. Any adjustments were therefore deemed inappropriate. Consequently, *all* information on both benefits and costs was used and presented as received.

There are many "grey areas" in collecting information on this subject. The extent of the analysis was difficult to delineate, regarding, for example, the role and use of suitable indicators for such things as environmental non-government organizations (ENGOs). While certain large national and international organizations have large budgets and make large contributions to the conservation of biodiversity, there are many more small organizations that do not undertake activities that can be readily associated with biodiversity as well as some that do. The number of ENGOs is large in Canada (over 2,000) but their role concerning biodiversity, except for the larger ones, has not been determined by this study. While the budgets of ENGOs can measure part of the contributions ENGOs make to biodiversity research, education, conservation and protection, that measure fails to take into the account the immense amount of voluntary time invested. In some organizations the value of voluntary time may equal or exceed the monetary budget.

APPENDIX 14

ASSUMPTIONS FOR THE CALCULATIONS OF UNMET NEEDS

The assumptions used to calculate the unmet needs for biodiversity conservation are summarized in this appendix. Since the numbers were not meant to be highly accurate, only the base facts are presented here. Each entry is keyed to the number in the text (see Chapter 7, Sections 7.3.1 and 7.3.2).

1.A a)
- 2,500 person-years of employment
- salary costs of $45,000 each per annum
- annual material and other associated costs of $20,000

1.A b) i.
- 300 professionals/technicians
- average of 6 years' education
- average cost per year per student of $7,500
- average total grant for research $10,000

1.A b) ii.
- 300 professionals/technicians
- average of 6 years' education
- average cost per year per student of $7,500

1.A b) iii.
- 300 professionals/technicians
- average of 6 years' education
- average cost per year per student of $7,500

1.A b) iv.
- 200 professionals/technicians
- average of 6 years' education
- average cost per year per student of $7,500

1.A b) v.
- 100 professionals/technicians
- average of 6 years' education
- average cost per year per student of $7,500

1.A b) vi.
- 50 person-years @ $50,000 per year
- ongoing, professors teaching in other faculties

1.A c)
- 1,000 environmental course participants per year
- for private and public sector executives

1.A d)
- 1,000 participants per year
- courses varying from one week to one month
- average of two weeks (1/16 cost of university student costs)
- support costs almost double student costs

1.B a)	• 500 researchers • assistance of $20,000 each
1.B b)	• estimated at $100 million over 5 years
1.B c)	• 10% increase to National Museum budget • $5 million for each of 9 provincial museums • 3 new museums (Quebec & territories): • $20 million for Quebec & $ 20 million for two territories
1.C a)	• estimated $30 million for each sector each year for 5 years
1.C b)	• estimated $1 million/year for 5 years
1.C c)	• estimated 10% increase over current spending
1.C d)	• estimated $10 million/year for 5 years
1.C e)	• estimated 25% increase in funding
1.C f)	• estimated $5 million required
1.C g)	• estimated $10 million in total • plus $1 million per year for 5 years
1.C h)	• not considered here
1.C i)	• estimated $5 million per year for 5 years
2. a)	• estimated 700 researchers @ $50,000 per year • estimated 700 technicians @ $40,000 per year • estimated $100,000 each researcher in costs • strengthening 1 national library and 20 regional libraries • $150,000 each plus 1 person-year @ $50,000
2. b)	• estimated $100 million per year for 5 years
2. c)	• estimated $10 million per year for 5 years
2. d)	• estimated $100 million per year for 5 years
2. e)	• estimated $20 million per year for 5 years
2. f)	• estimated $20 million per year for 5 years
2. g)	• estimated $5 million contingency fund
2. h)	• estimated $3 million per year for 5 years

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Ted is a long-time naturalist and applied ecologist. He is the President of *Ecospherics International Inc.*, a firm that organizes and supports the *Ecospherics Consulting Group*. Ted has served as Editor of *Canadian Field-Naturalist* and *Nature Canada* and also organized a key national symposium on *Canada's Threatened Species and Habitats* for the Canadian Nature Federation and the World Wildlife Fund. He is co-author of *Legacy: A Natural History of Ontario* and *On the Brink: Endangered Species in Canada.*

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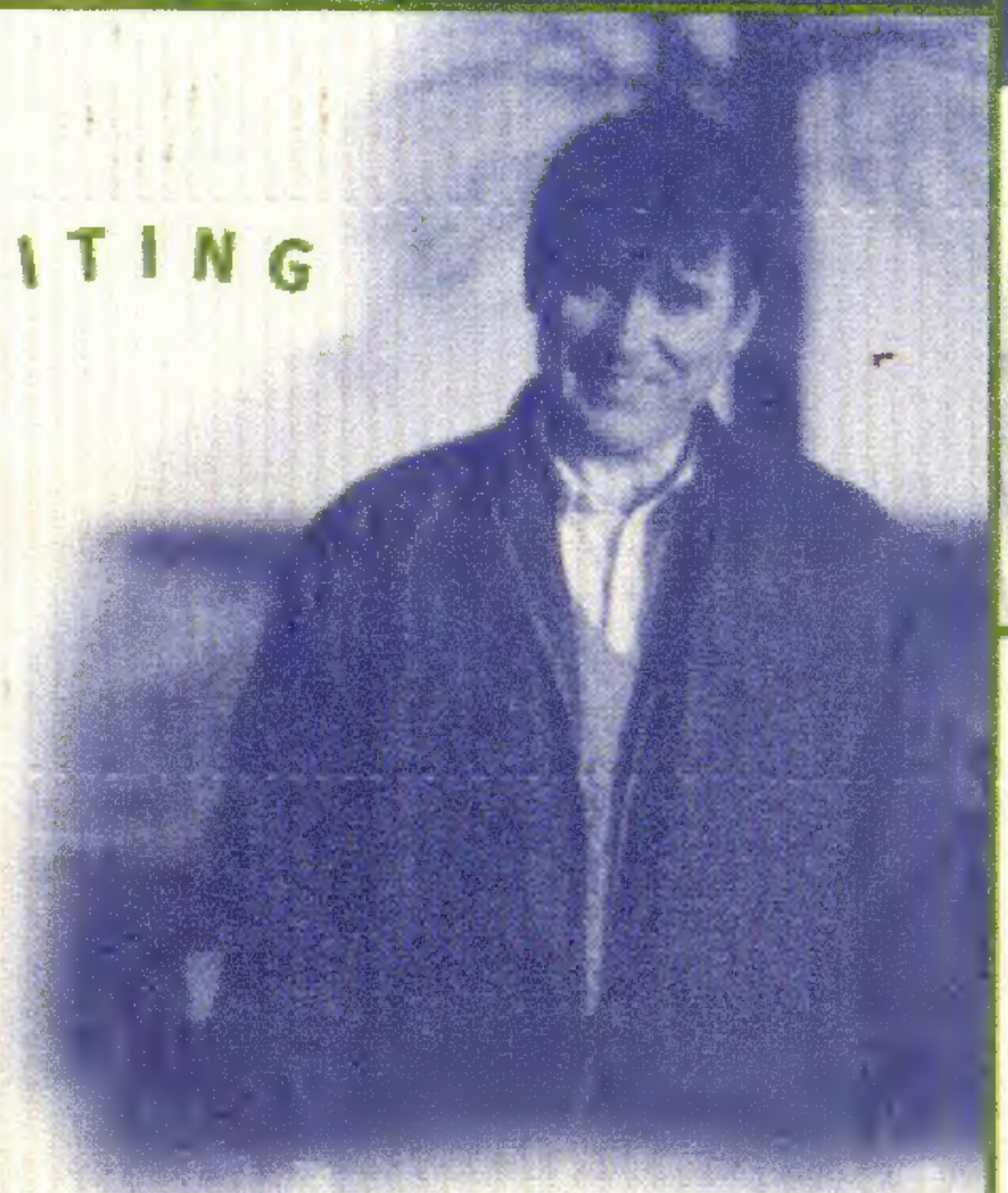

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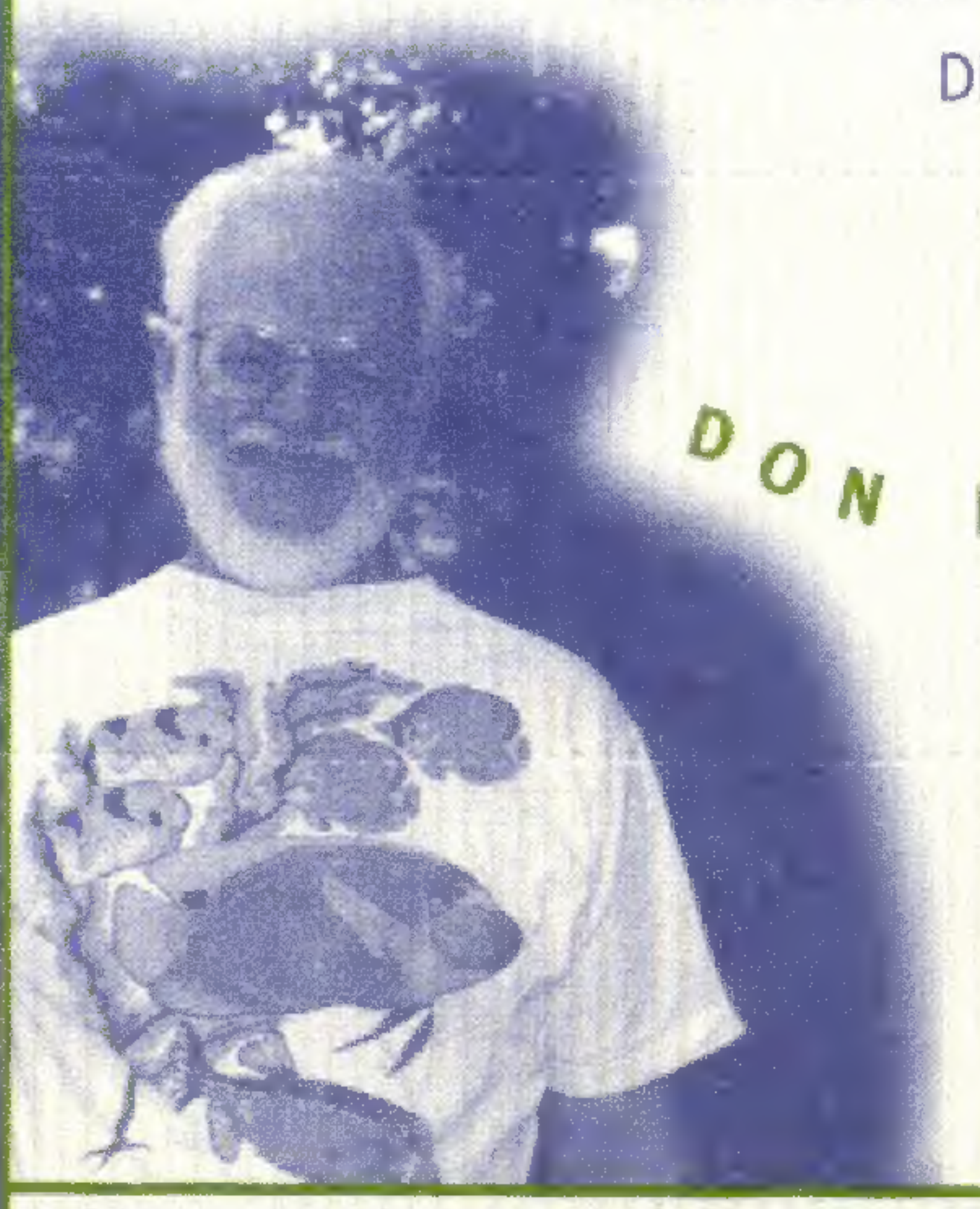

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ISBN 0-660-13073-4

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